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COMPILATION OF ULTRAVIOLET PHOTOABSORPTION CROSS SECTIONS FOR ATOMS BETWEEN 5 AND 3500 Å

HUDSON and KIEFFER

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COMPILATION OF ULTRAVIOLET PHOTOABSORPTION CROSS SECTIONS FOR ATOMS BETWEEN 5 AND 3500 Å

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Foreword

As NOTED ELSEWHERE, this report represents the cooperative effort of the NASA Manned Spacecraft Center and the Information Center of the University of Colorado's Joint Institute for Laboratory Astrophysics. Graphical displays of selected experimental data on atomic photoabsorption cross sections as a function of wavelength are presented for 24 atoms. The criteria used in the data selection are discussed, and the report contains a complete citation index. The data displayed are current as of October 1969.

R. D. H.
L. J. K.

Contents

Introduction

DURING THE PAST SEVERAL YEARS, the Information Center of the Joint Institute for Laboratory Astrophysics (JILA),[1] University of Colorado, Boulder, Colo., has been engaged in a program of critically evaluating the reliability of cross-section data for many atomic and molecular processes and in producing comprehensive compilations of these data. This report, the result of a joint effort between the JILA Information Center and the NASA Manned Spacecraft Center, is a compilation of ultraviolet photoabsorption cross sections for atoms between 5 and 3500 Å. The compilation is limited to experimental measurements only and includes data for all atomic species that have been measured within this energy range. The literature was searched for data through October 1969; however, because the Information Center covers some material through abstracting journals, a few measurements may not be included.

A complete bibliography is not given in this report, but one is contained in reference 1. It is obvious, therefore, that some selection of the data has taken place. This selection was made on the basis of the inherent reliability of the measurement technique used in the determination. The data in the literature that have not been included in this compilation were rejected for one of two reasons: either the data were not the result of an absolute measurement (or not normalized to an absolute value) or other results existed that were obtained by more reliable methods.

The authors gratefully acknowledge the assistance of Elizabeth Reynolds, Lois Spangenberg, Victoria Tempey, and Patricia Ruttenberg in the preparation of the figures and bibliography for this report.

EXPERIMENTAL UNCERTAINTY

A detailed discussion of the systematic errors inherent in photoabsorption cross-section measurements is given in reference 2. From the description

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[1] The JILA Information Center is supported in part by the National Bureau of Standards through the National Standard Reference Data program and in part by the Advanced Research Projects Agency of the Department of Defense (monitored by the Army Research Office, Durham) under contract DA-31-124-ARO-D-139.

of the experimental techniques used to obtain the data displayed in this compilation and from the authors' estimates of their total errors, it is concluded that many sources of systematic errors were not taken into account in the authors' error analyses. In those wavelength regions in which structure is observed, there is often a large uncertainty in the absolute magnitude as well as in the shape of the curves caused by the averaging effect of the finite bandwidth of the instrument used in the measurement. As has been shown by Hudson and Carter (ref. 3), bandwidth dependence of measured cross sections often can lead to systematic errors of a factor of 2 in peak cross sections. The atoms and the respective wavelength intervals for which structure has been observed are listed in table I.

TABLE I.—*Atoms, With Respective Wavelength Intervals, for Which Structure Has Been Observed*

Species	Wavelength interval, Å	Reference	Species	Wavelength interval, Å	Reference
He	260 to 190	4	K	612 to 664	14
	165 to 200	5	Zn	708 to 1320	15
N	610 to 700	6	Ga	1500 to 2067	16
O	660 to 910	7	Kr	845 to 886	11
Ne	570 to 585	8		387 to 498	17
	200 to 280		Xe	920 to 1025	11
Al	1740 to 1950	9		165 to 390	18
Si	1514 to 1550	10	Ba	1650 to 2380	19
Ar	777 to 788	11			
	210 to 466	12, 13			

CHOICE OF GRAPHICAL DISPLAY

The data in this report are displayed in graphical form (figs. 1 through 26). In cases in which there are several measurements, it is believed that this form of display emphasizes the disagreement and acts as a warning to the users. The precision of these data far exceeds the accuracy, and a tabular presentation would tend to convince the reader that the second or third figures are significant, whereas they are not. It is realized that the graphical mode of presentation makes the use of these data somewhat difficult but, at present, it is believed that the advantages outweigh the disadvantages.

Almost all the data included in this compilation were presented in the original literature in graphical form. If tabular data were made available by the authors, these data were used; however, in general, the effort to

obtain tabular data from the authors, especially for the older experiments, was so inefficient that it was abandoned. In most cases, blown-up photographs of the figures were made and the data were digitized by means of an x-y reader that was connected to a card punch. The least count of the reader was 0.1 percent full scale. This uncertainty becomes significant when the cross sections plotted are less than 10 percent full scale; but, with our estimates of the accuracy of the original data, these errors would appear, in general, to be insignificant. After the digital data had been obtained, they were permanently stored on magnetic tape. The figures then were photocomposed from these tapes on a microfilm-output device (MOD) (a cathode-ray tube) at the Environmental Science Services Administration (ESSA) Boulder Laboratories computing facility. Because the MOD is a very high speed device, the possibility of a plotting error exists. The errors caused by digitizing and plotting amount to less than 0.5 percent full scale for each figure.

ORGANIZATION OF THE COMPILATION

The data shown in this compilation have been ordered by atomic number Z with the smallest Z first. In all cases, the data have been reproduced as originally published; that is, if originally published as lines, the data have been reproduced as solid or dotted lines, and if originally published as points (or in tabular form), the data have been reproduced as points. A somewhat arbitrary decision has been made to distinguish between measured photoabsorption and photoionization cross sections because of the fundamental difference in the measurement techniques. In a few cases, some ionization cross sections that were measured using photoabsorption techniques have had to be relabeled.

The cross section for a particular atomic species X is indicated in the upper right-hand corner of each figure by the label $\sigma_L(X)$ where L is either A for photoabsorption or i for photoionization. The ordinate of each figure gives the cross section in square centimeters and the abscissa gives the wavelength scale in angstroms (10^{-8} cm). The experiment from which the data were obtained is identified by the name of the first author, followed by the number (in parentheses) assigned to the original paper in the bibliography of reference 1. The same number is used in the bibliography of this report where the full citation may be found. Any specific notes about the experiments are included in the figure captions.

The last section of this report is an author index that lists all authors. Each author's name is followed by the citation numbers of all his publications from which data were obtained.

Ultraviolet Cross Sections for Atoms

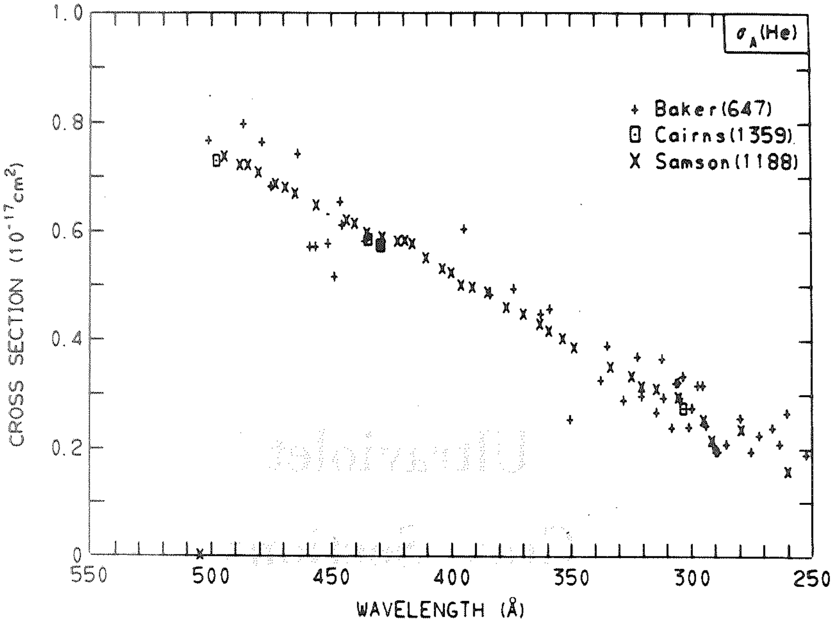

FIGURE 1.—Total absorption cross section of helium. (*a*) 250 to 550 Å.

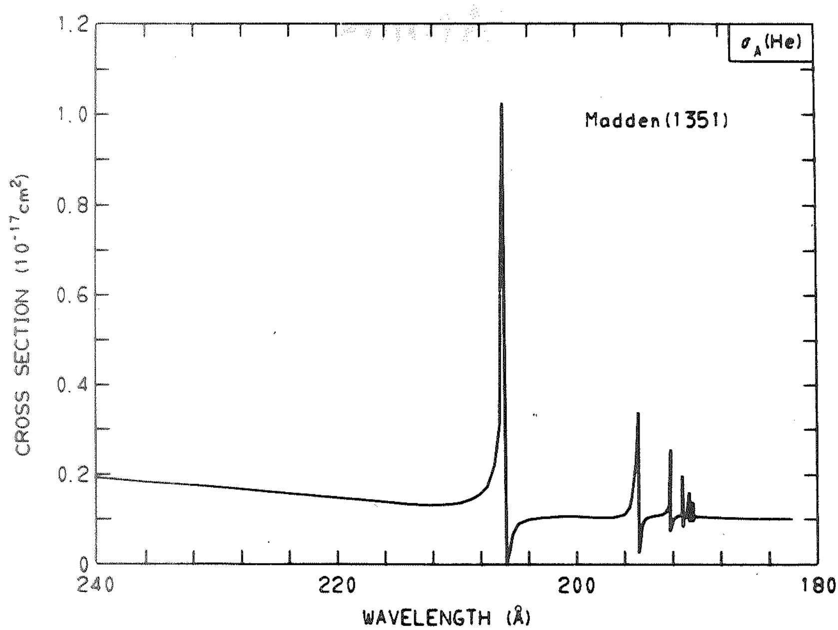

FIGURE 1 (continued).—(*b*) 180 to 240 Å.

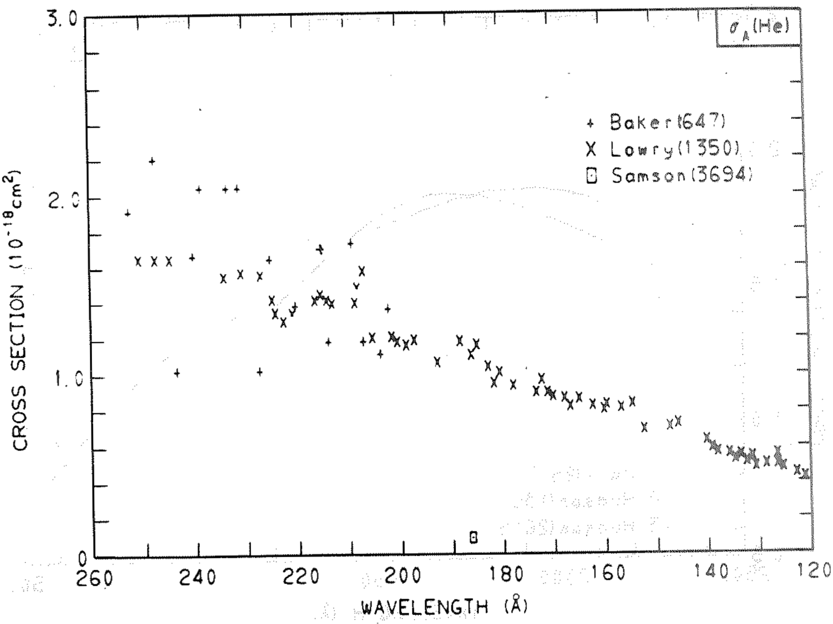

FIGURE 1 (continued).—(*c*) 120 to 260 Å.

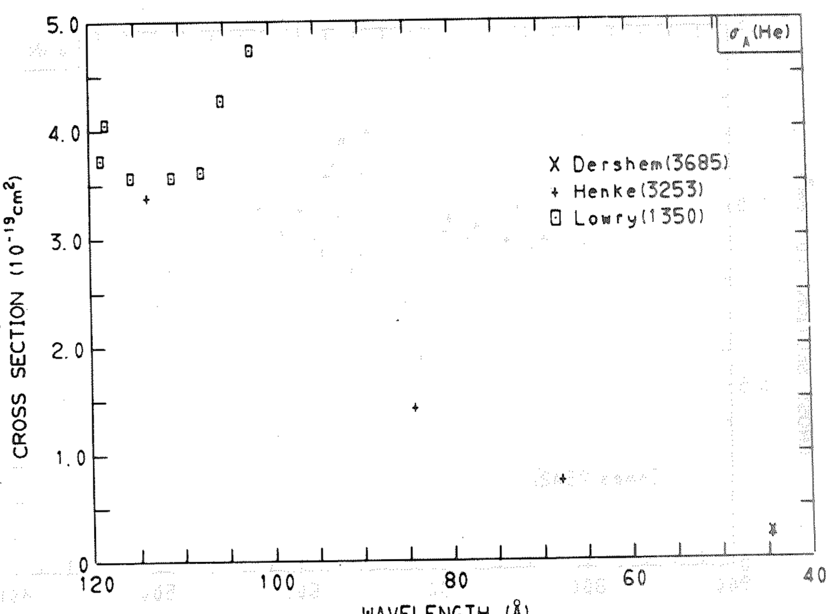

FIGURE 1 (concluded).—(*d*) 40 to 120 Å.

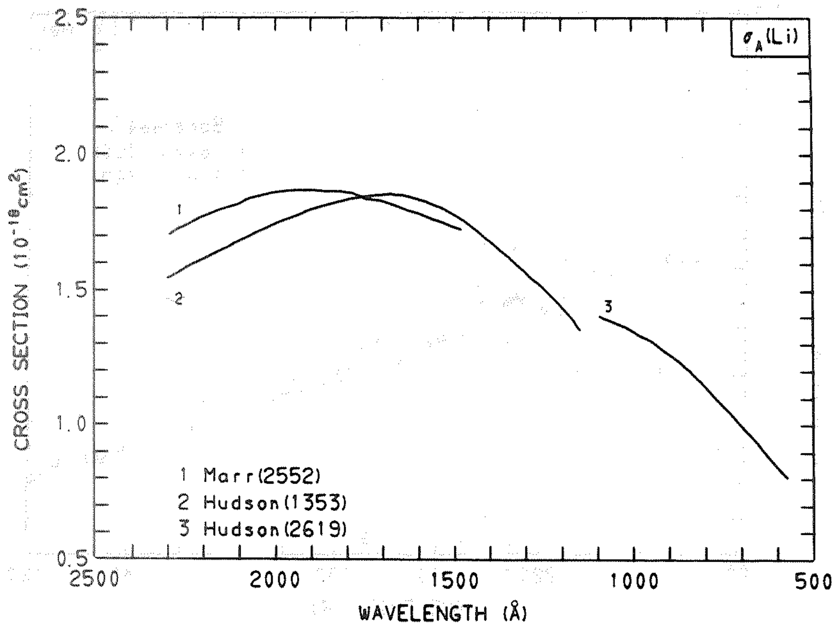

FIGURE 2.—Total absorption cross section of lithium, 500 to 2500 Å.

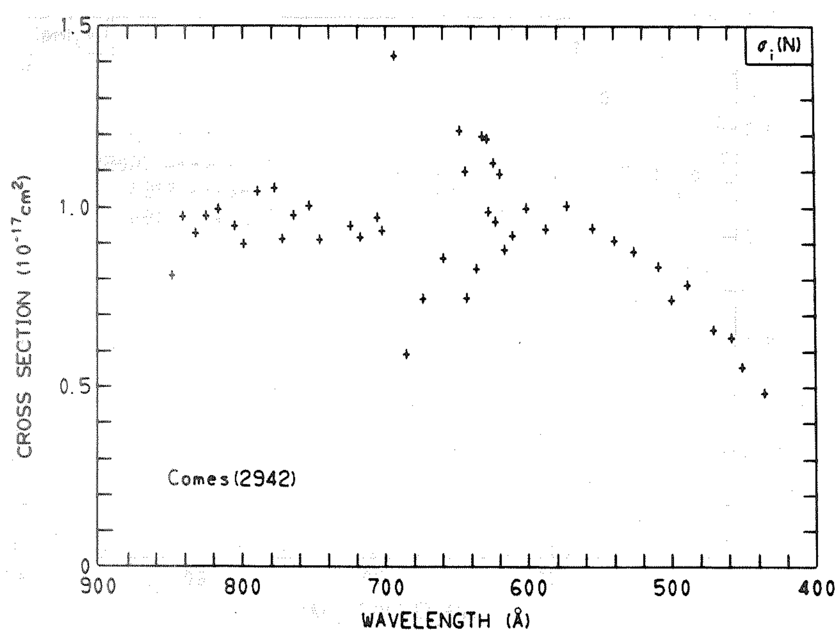

FIGURE 3.—Ionization cross section of atomic nitrogen, 400 to 900 Å.

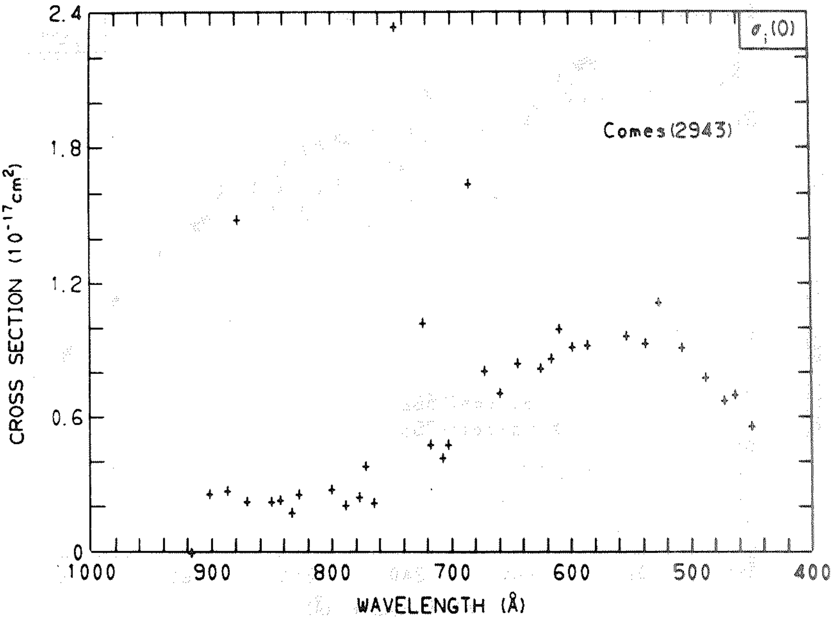

FIGURE 4.—Ionization cross section of atomic oxygen, 400 to 1000 Å.

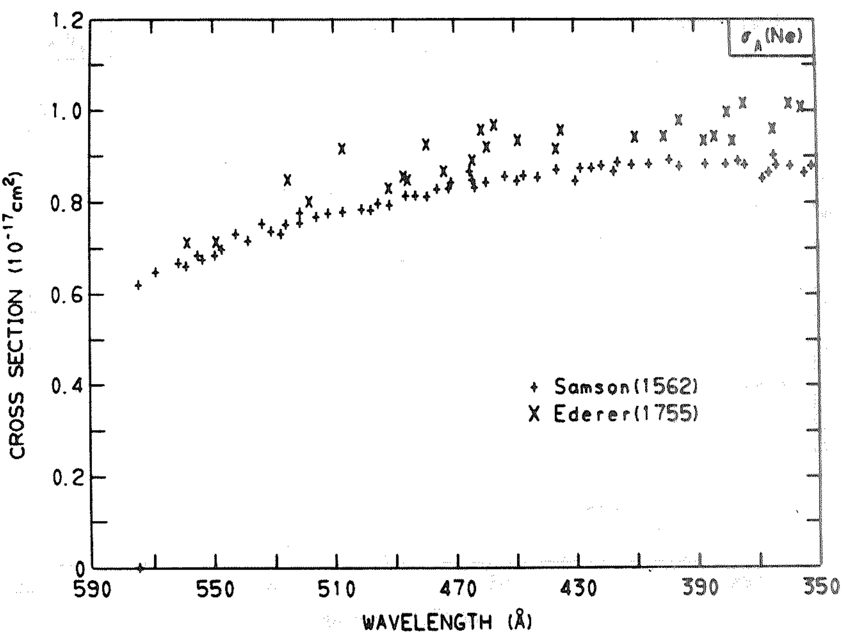

FIGURE 5.—Total absorption cross section of neon. (*a*) 350 to 590 Å.

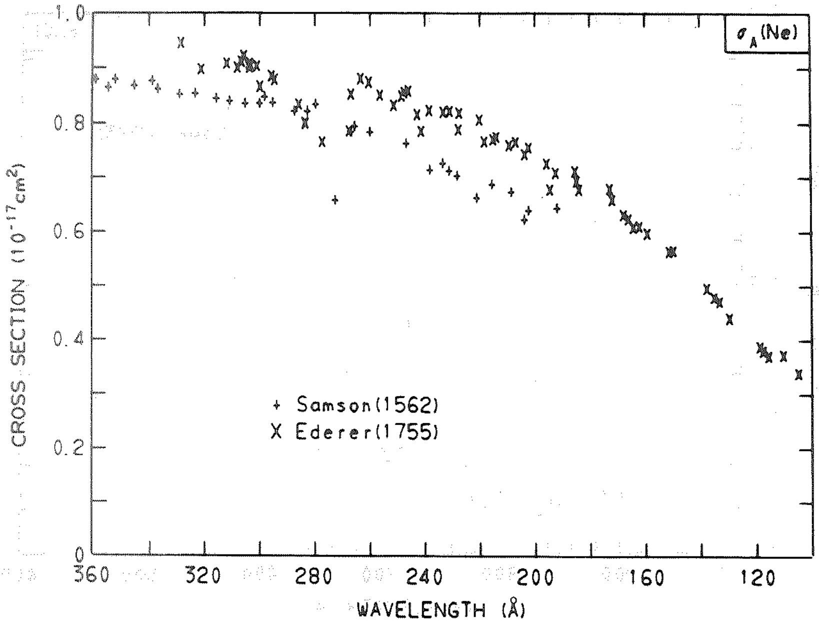

FIGURE 5 (continued).—(*b*) 100 to 360 Å.

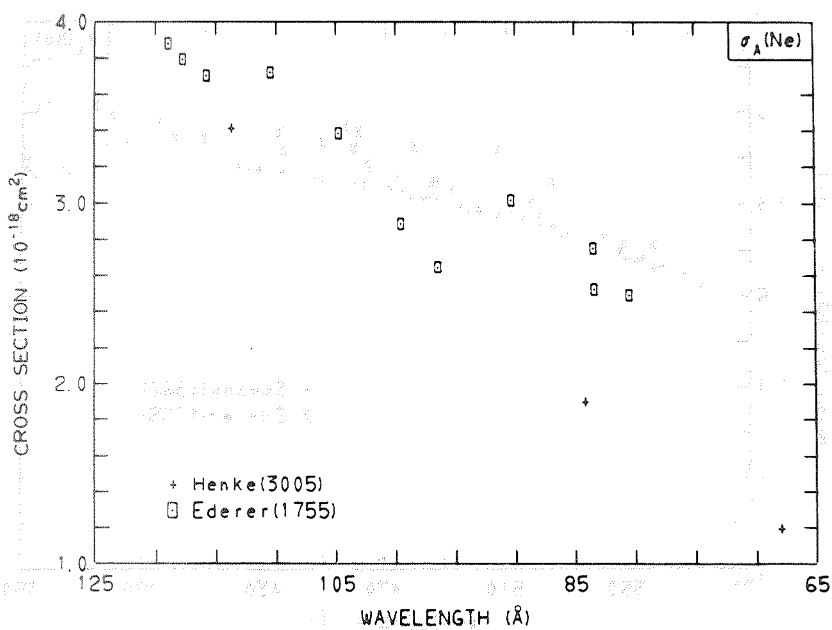

FIGURE 5 (continued).—(*c*) 65 to 125 Å.

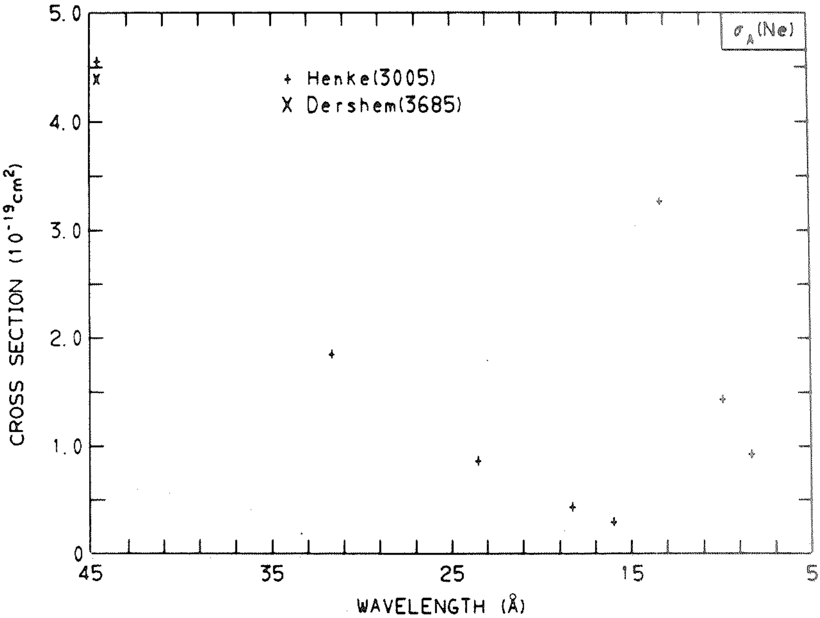

FIGURE 5 (concluded).—(*d*) 5 to 45 Å.

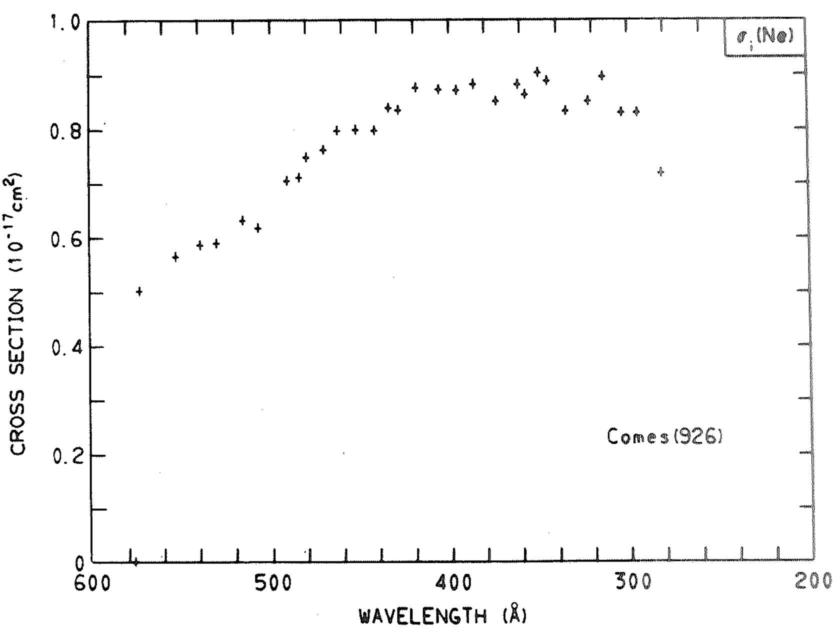

FIGURE 6.—Ionization cross section of neon, 200 to 600 Å.

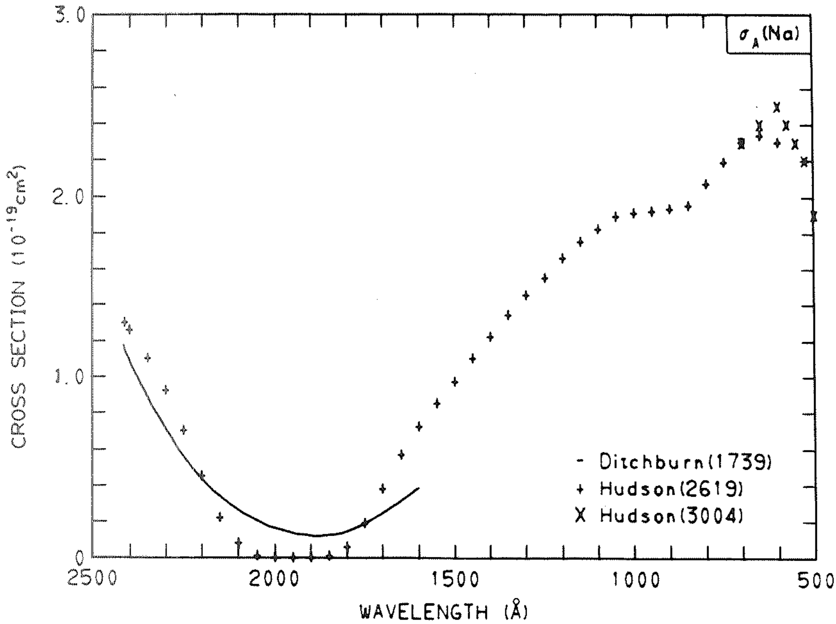

FIGURE 7.—Total absorption cross section of sodium, 500 to 2500 Å.

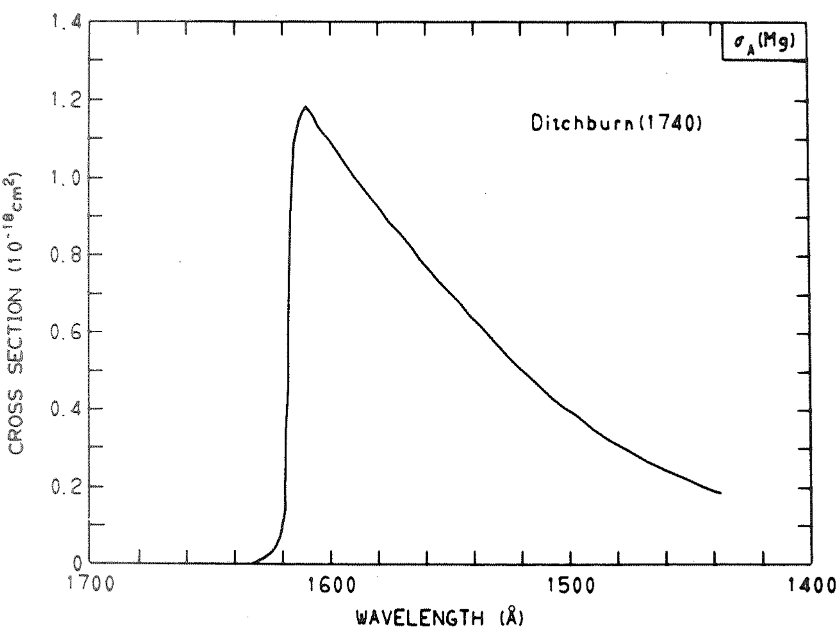

FIGURE 8.—Total absorption cross section of magnesium, 1400 to 1700 Å.

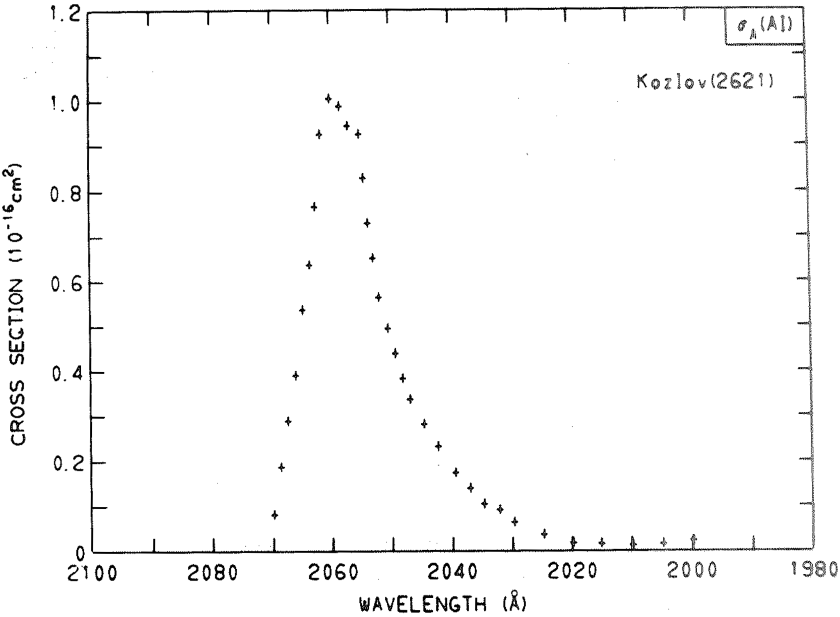

FIGURE 9.—Total absorption cross section of aluminum. (*a*) 1980 to 2100 Å.

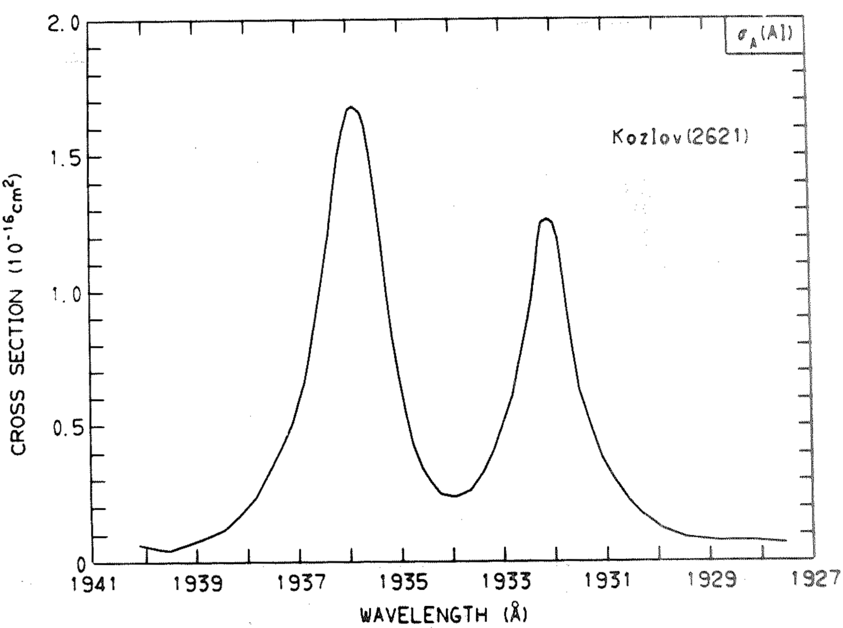

FIGURE 9 (continued).—(*b*) 1927 to 1941 Å.

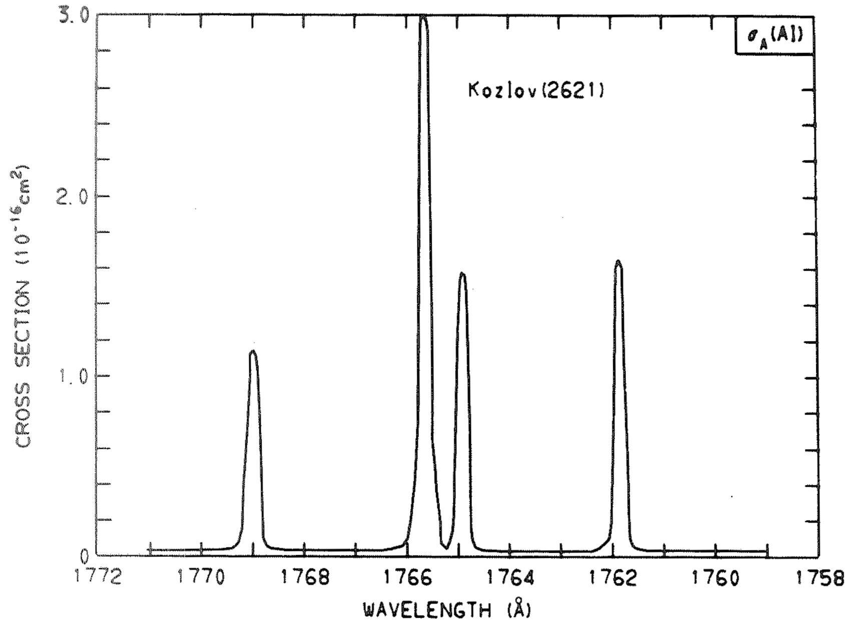

FIGURE 9 (concluded).—(c) 1758 to 1772 Å.

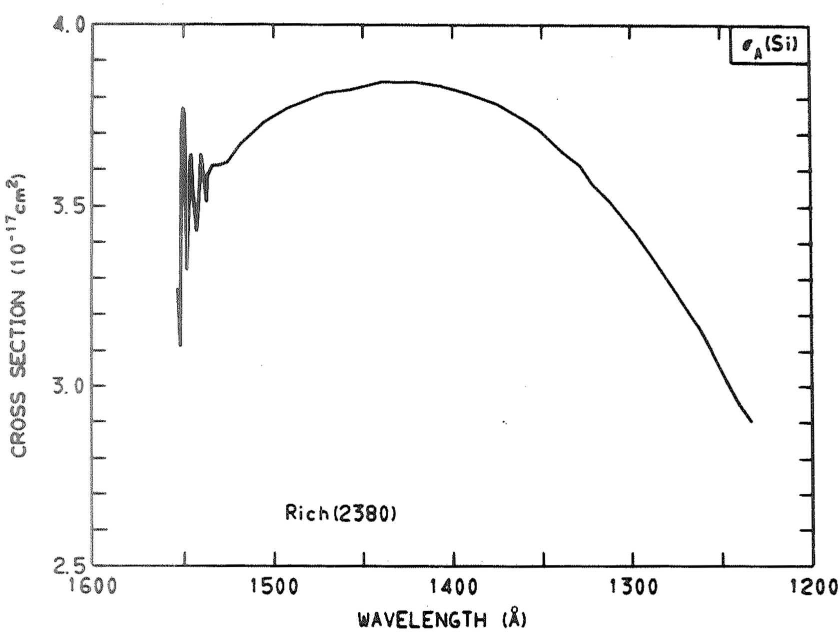

FIGURE 10.—Total absorption cross section of silicon, 1200 to 1600 Å.

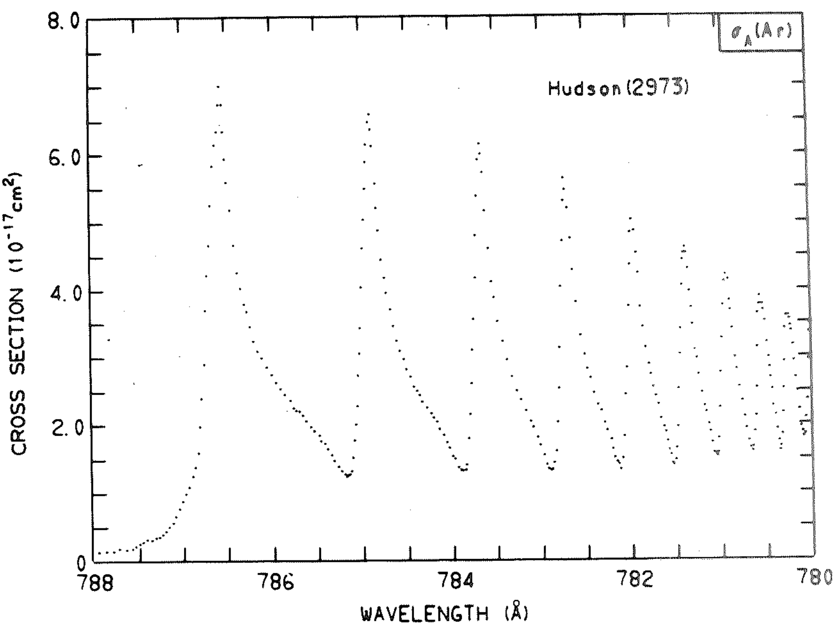

FIGURE 11.—Total absorption cross section of argon. (*a*) 780 to 788 Å.

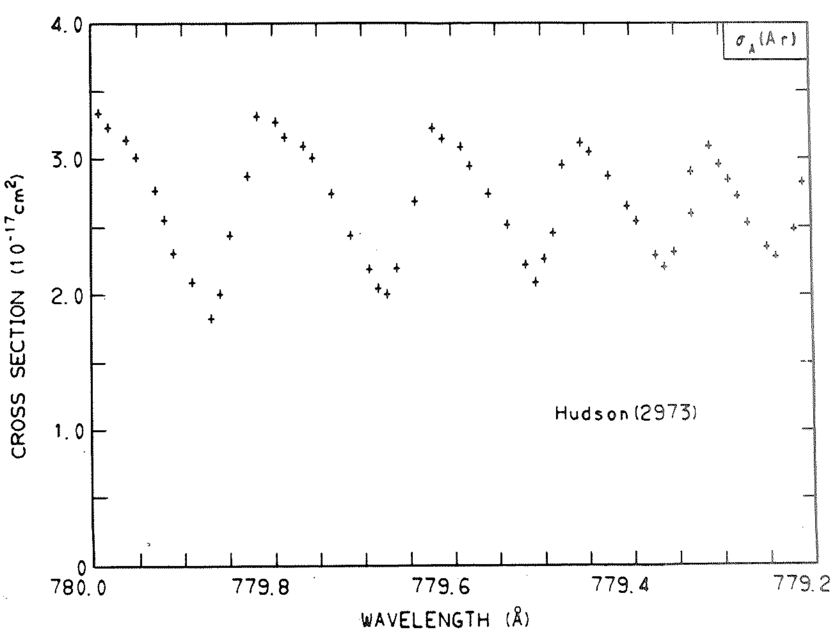

FIGURE 11 (continued).—(*b*) 779.2 to 780.0 Å.

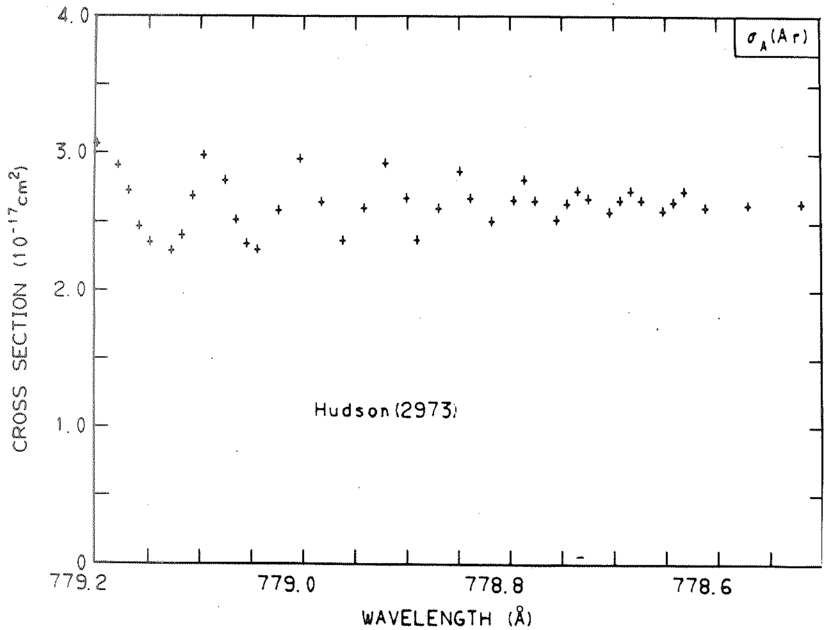

FIGURE 11 (continued).—(*c*) 778.5 to 779.2 Å.

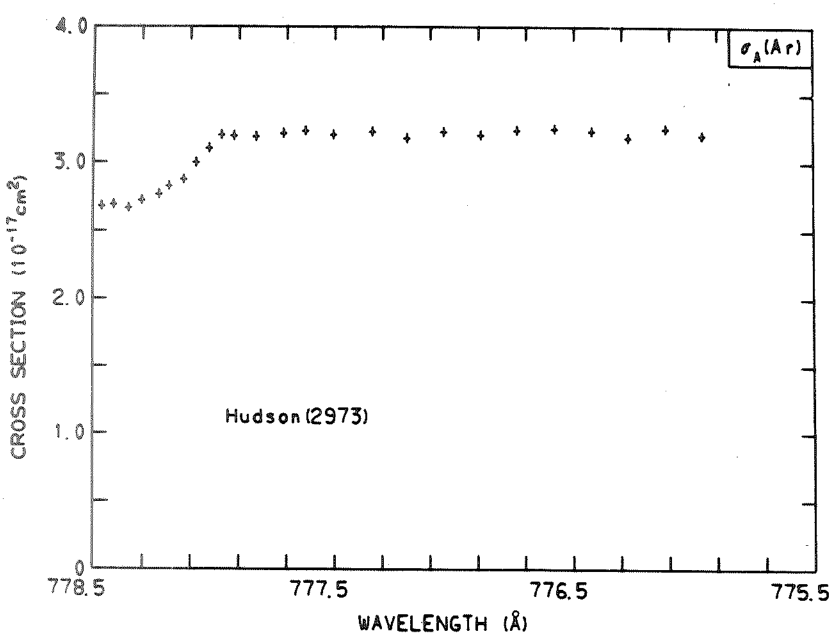

FIGURE 11 (continued).—(*d*) 775.5 to 778.5 Å.

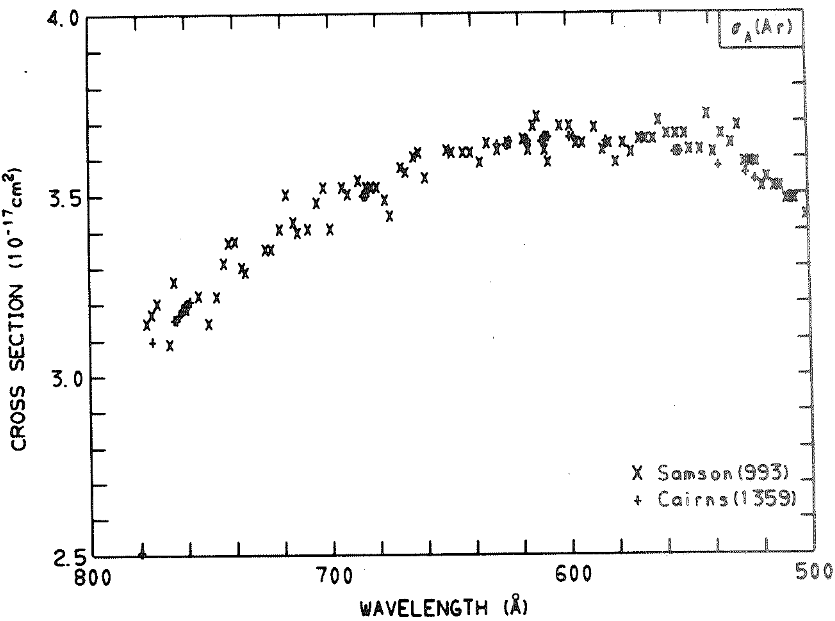

FIGURE 11 (continued).—(*e*) 500 to 800 Å.

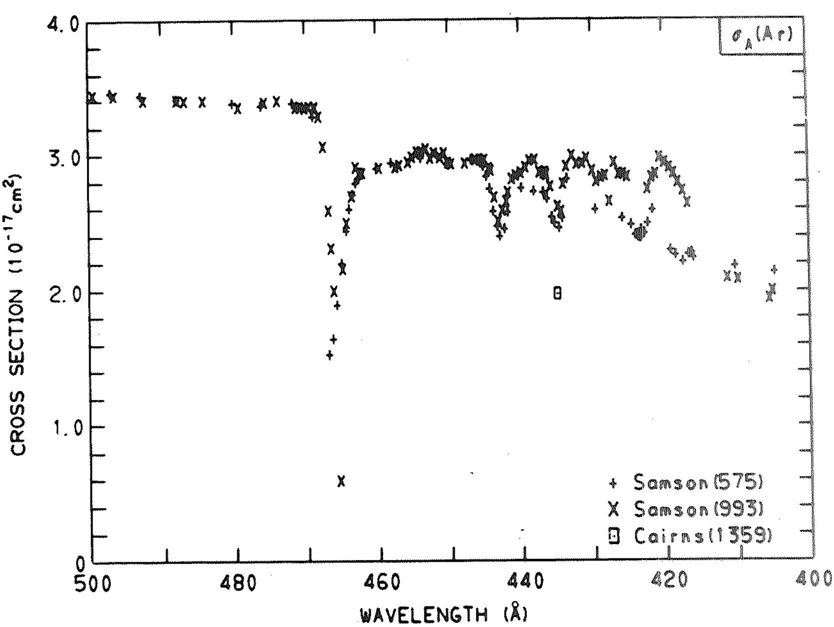

FIGURE 11 (continued).—(*f*) 400 to 500 Å.

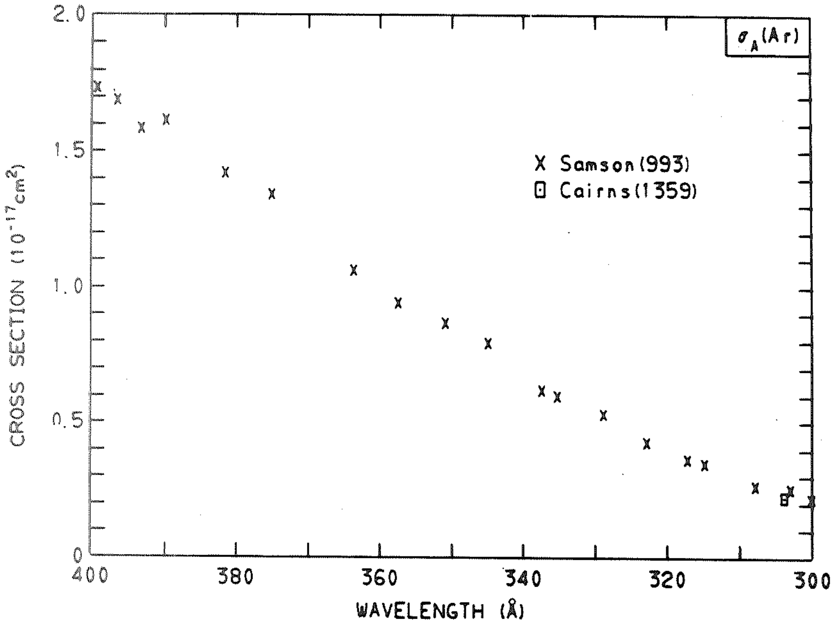

FIGURE 11 (continued).—(*g*) 300 to 400 Å.

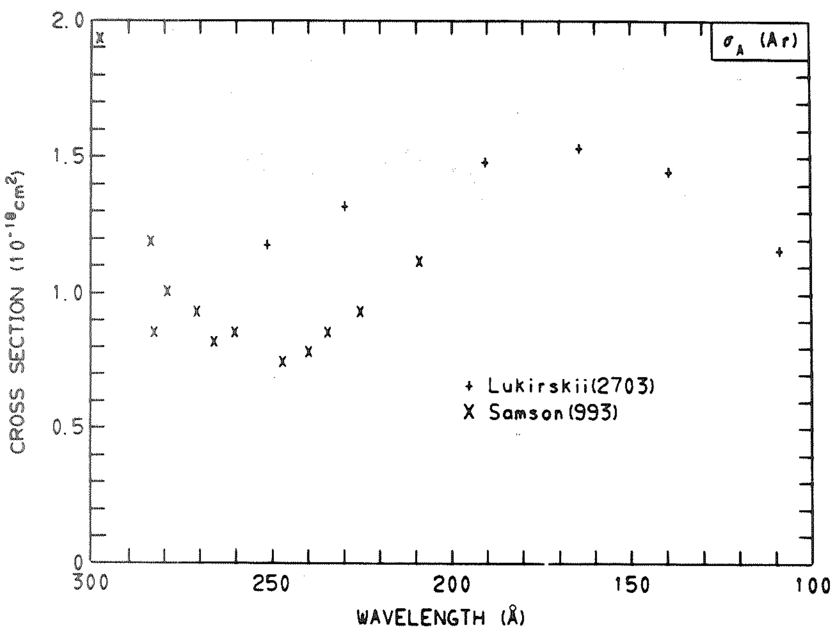

FIGURE 11 (continued).—(*h*) 100 to 300 Å.

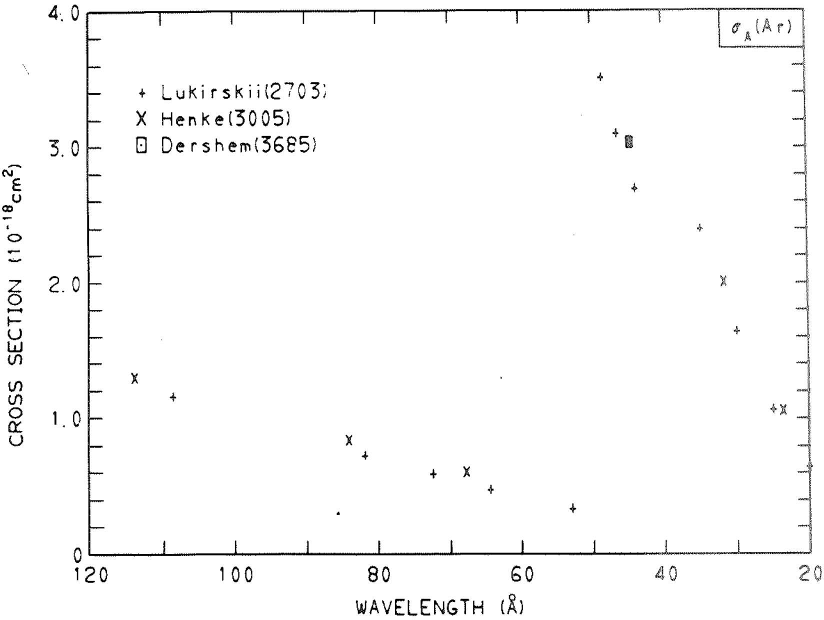

FIGURE 11 (continued).—(*i*) 20 to 120 Å.

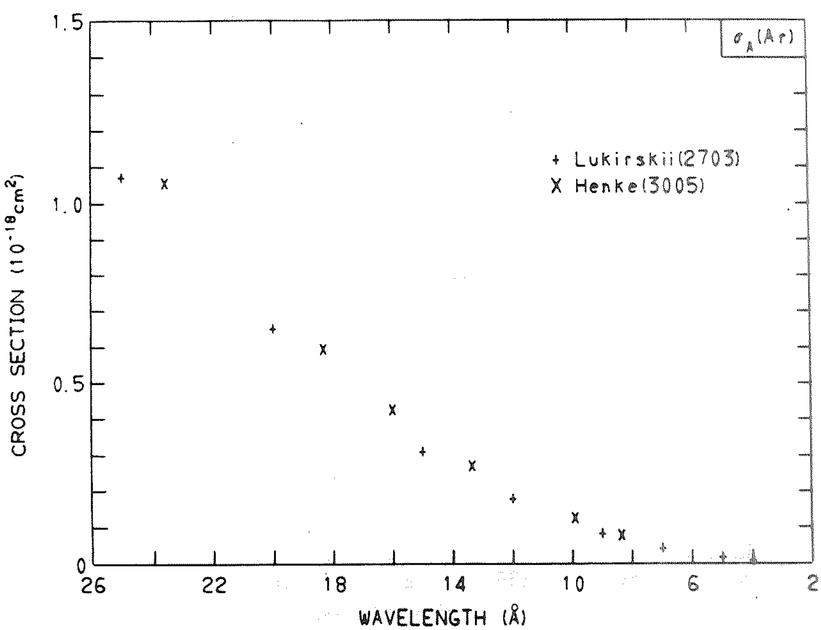

FIGURE 11 (concluded).—(*j*) 2 to 26 Å.

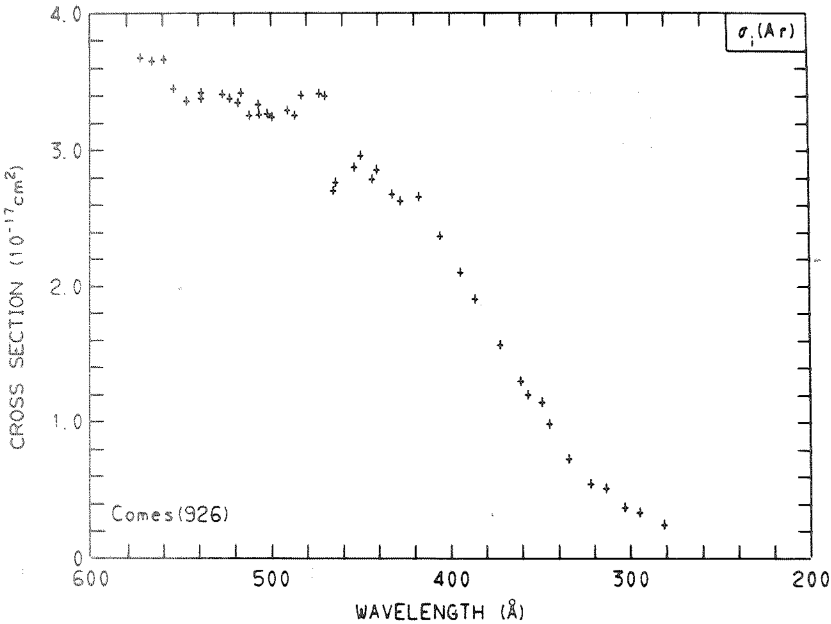

Figure 12.—Ionization cross section of argon, 200 to 600 Å.

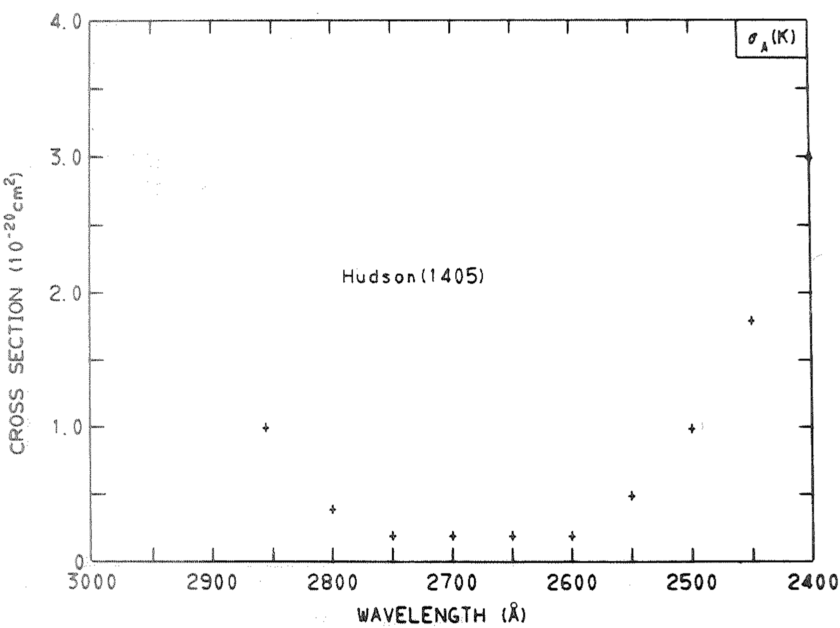

Figure 13.—Total absorption cross section of potassium. (*a*) 2400 to 3000 Å.

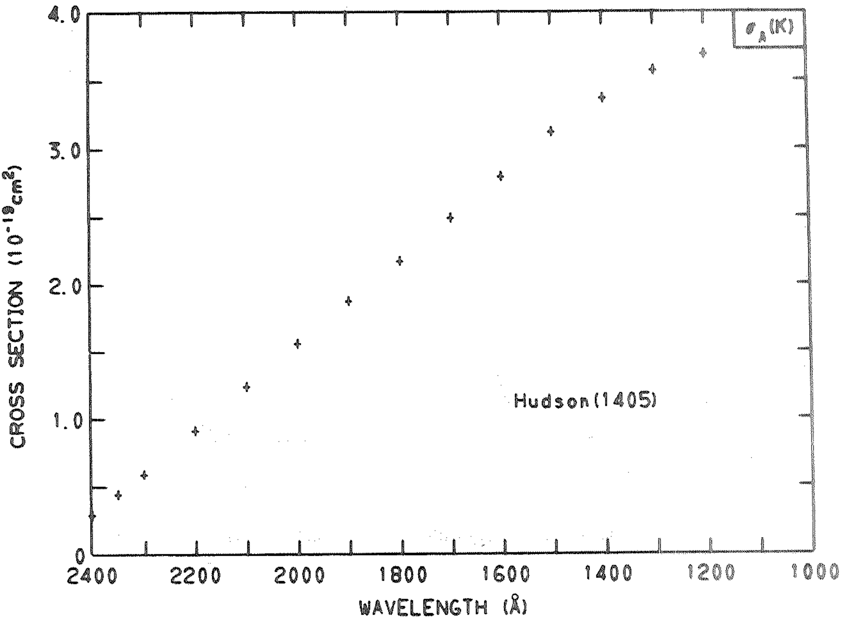

FIGURE 13 (continued).—(*b*) 1000 to 2400 Å.

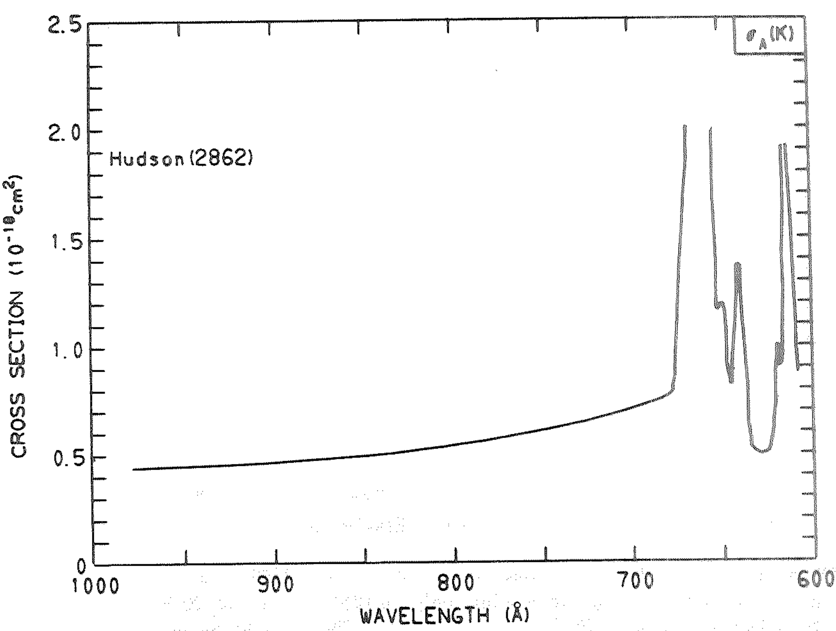

FIGURE 13 (continued).—(*c*) 600 to 1000 Å.

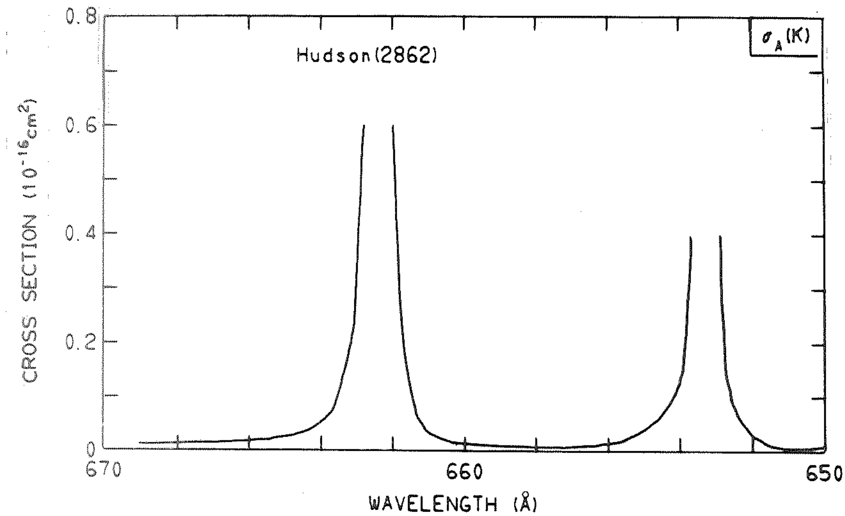

FIGURE 13 (concluded).—(*d*) 650 to 670 Å.

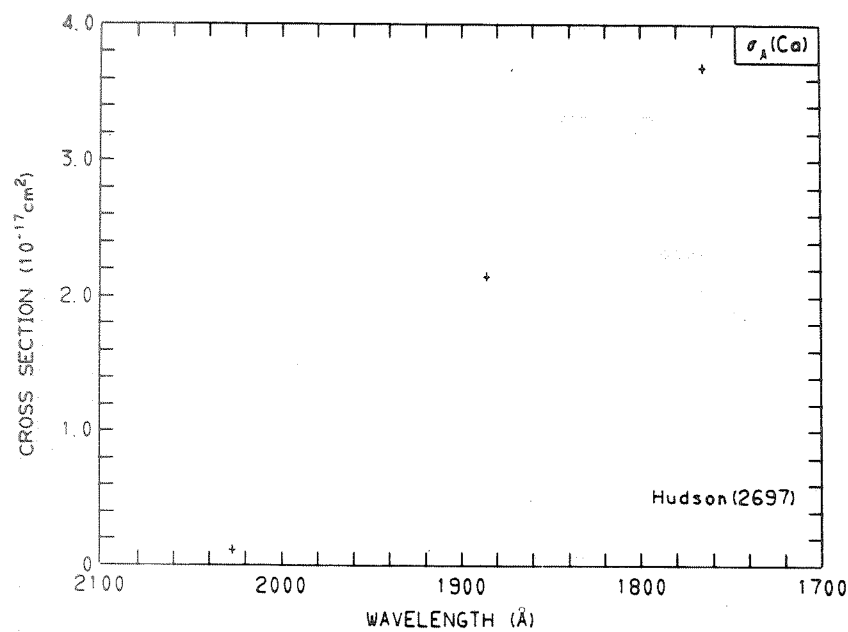

FIGURE 14.—Total absorption cross section of calcium, 1700 to 2100 Å. Hudson (2697) gives absolute values of three points only (0.12×10^{-17} cm^2 at 2028 Å, 2.15×10^{-17} cm^2 at 1885.9 Å, and 3.7×10^{-17} cm^2 at 1765.1 Å). These could be used to normalize the relative data of Newson (ref. 20).

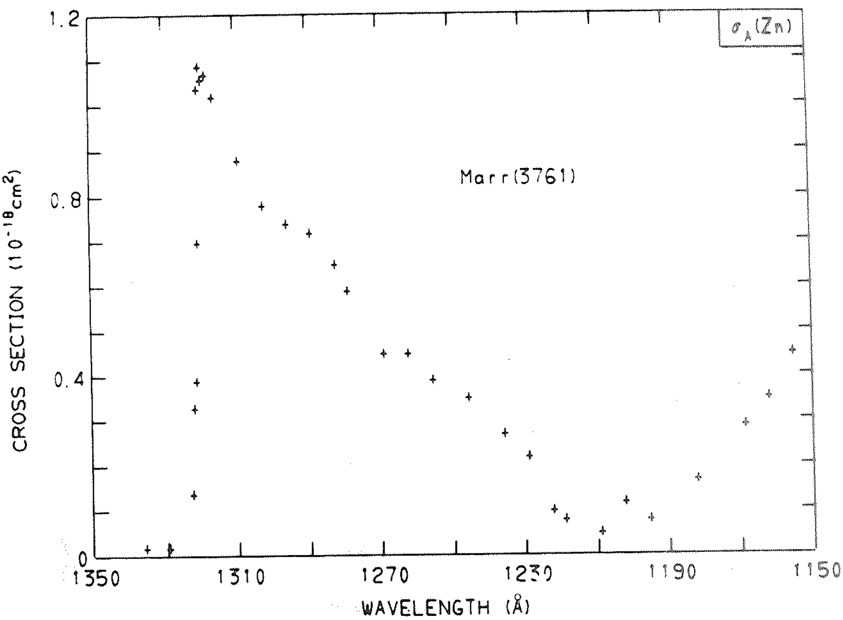

FIGURE 15.—Total absorption cross section of zinc. (*a*) 1150 to 1350 Å.

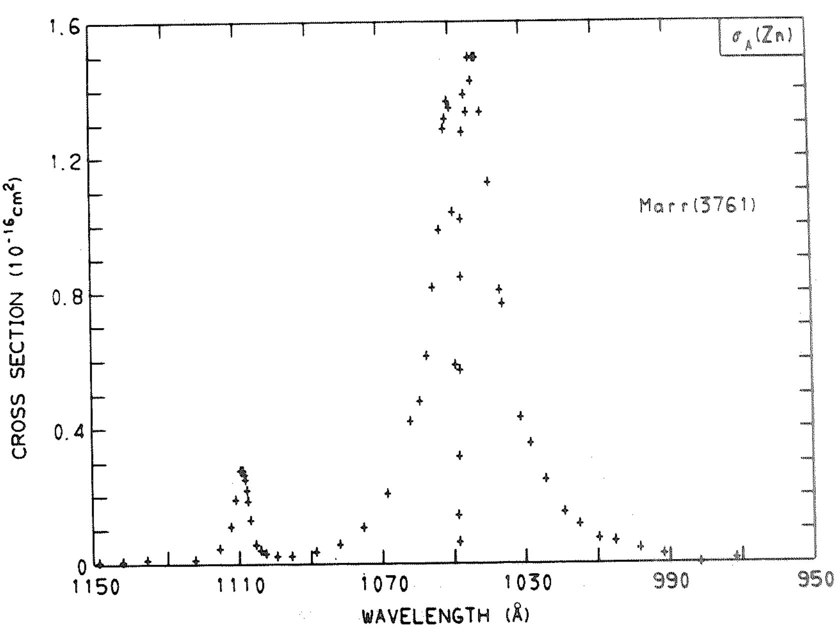

FIGURE 15 (continued).—(*b*) 950 to 1150 Å.

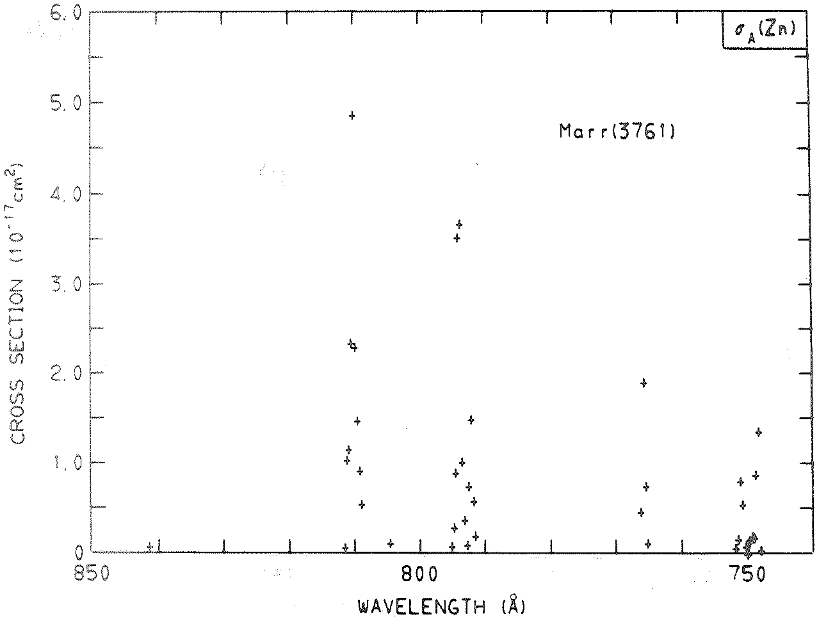

FIGURE 15 (concluded).—(*c*) 740 to 850 Å.

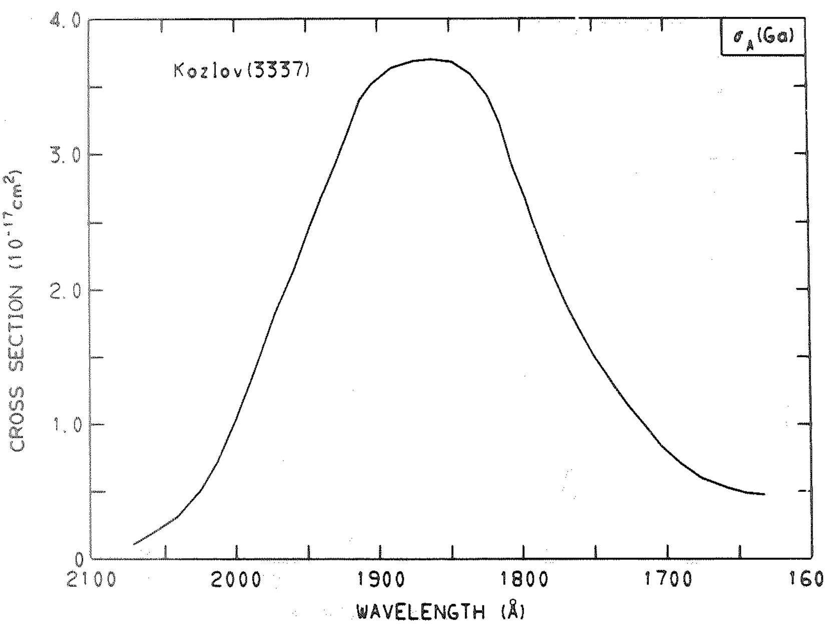

FIGURE 16.—Total absorption cross section of gallium. (*a*) 1600 to 2100 Å.

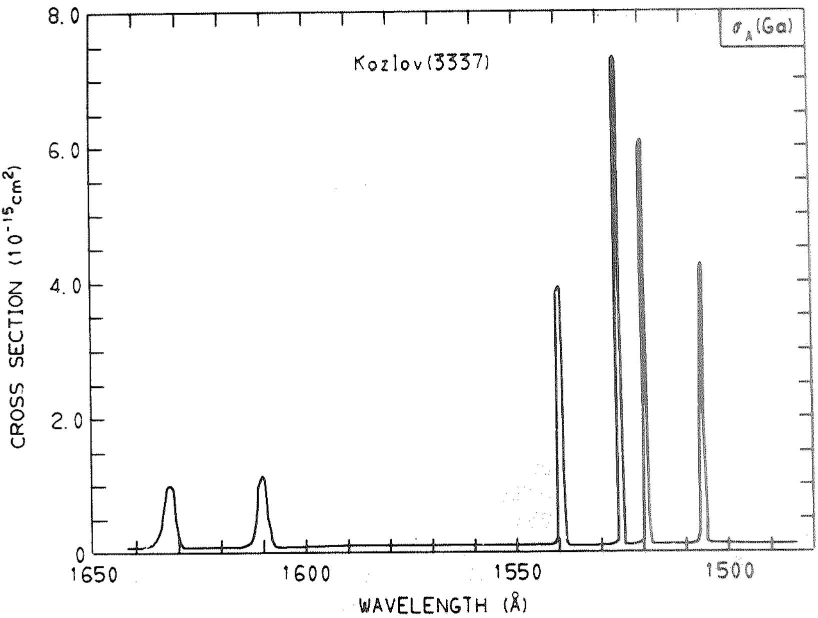

FIGURE 16 (concluded).—(*b*) 1480 to 1650 Å.

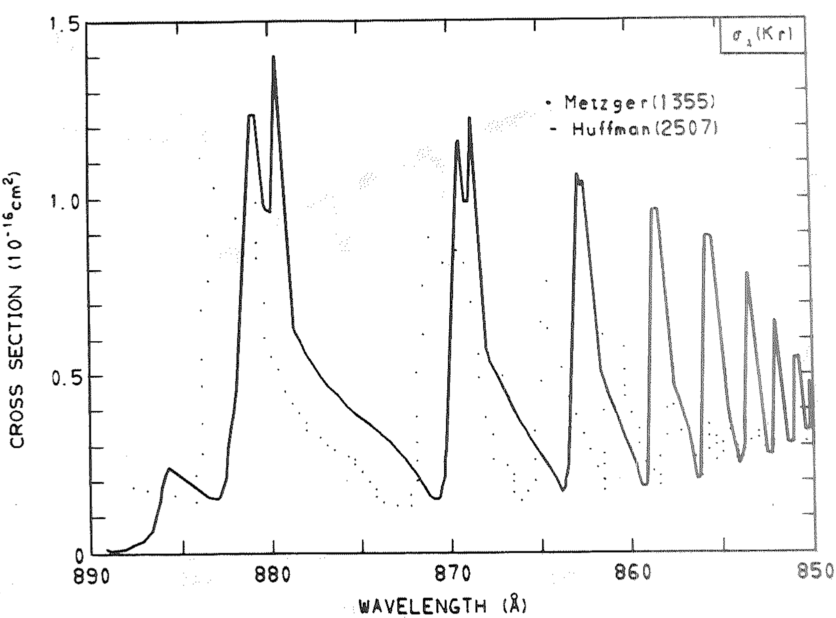

FIGURE 17.—Total absorption cross section of krypton. (*a*) 850 to 890 Å.

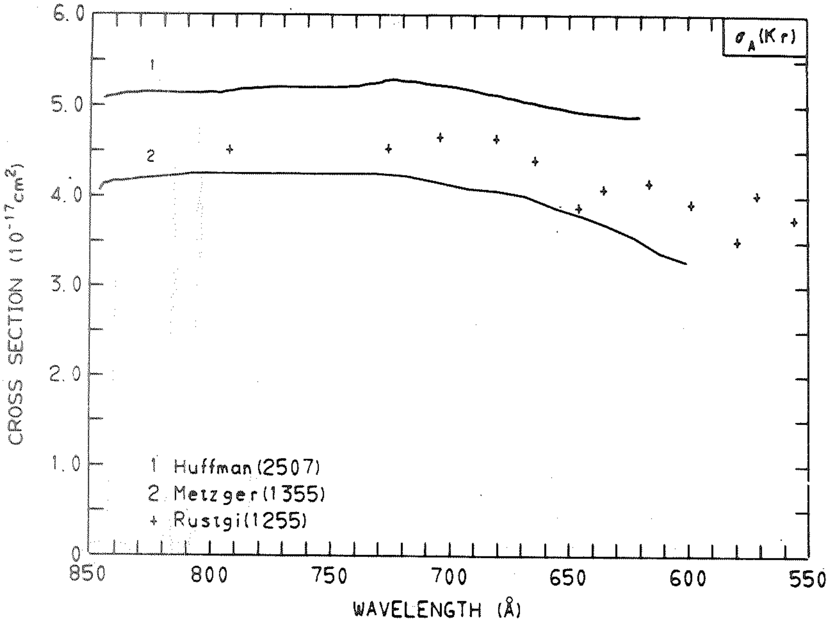

FIGURE 17 (continued).—(*b*) 550 to 850 Å.

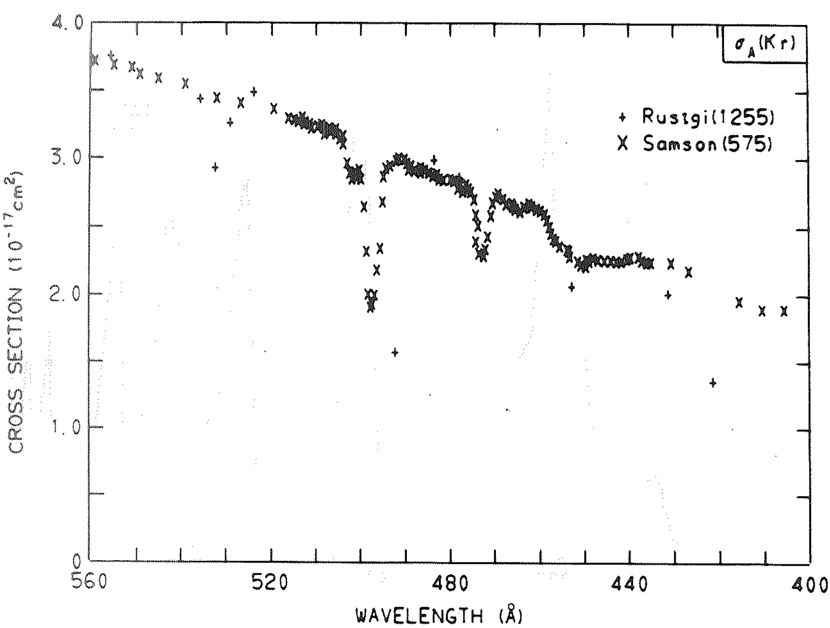

FIGURE 17 (continued).—(*c*) 400 to 560 Å.

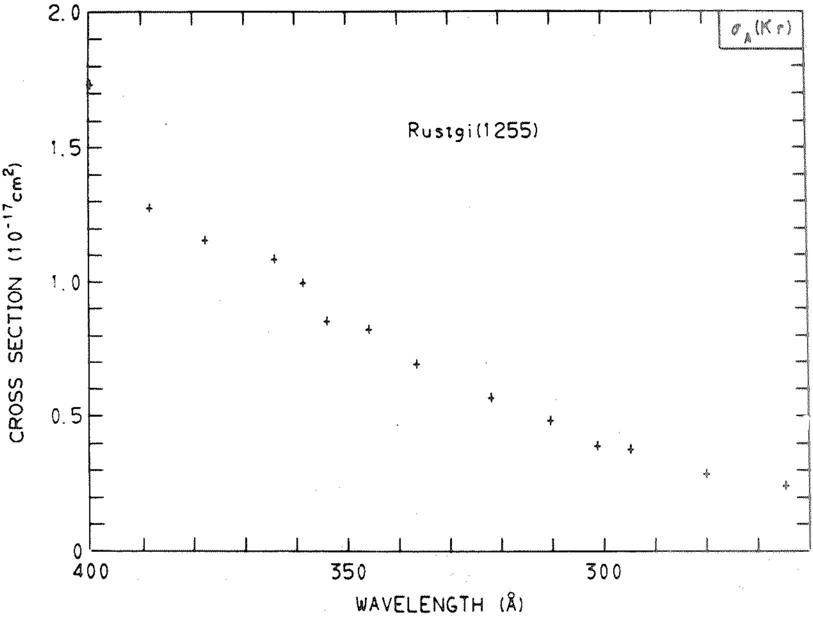

FIGURE 17 (continued).—(*d*) 260 to 400 Å.

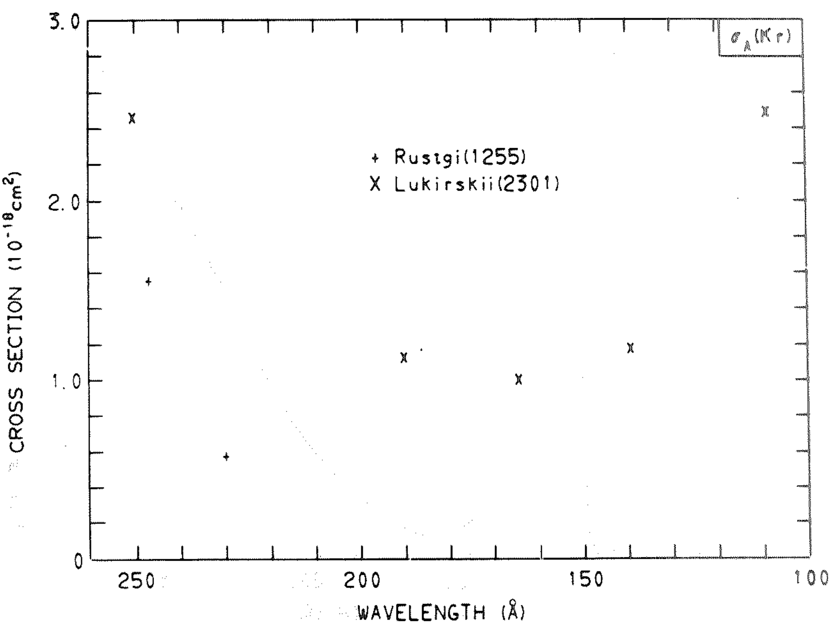

FIGURE 17 (continued).—(*e*) 100 to 260 Å.

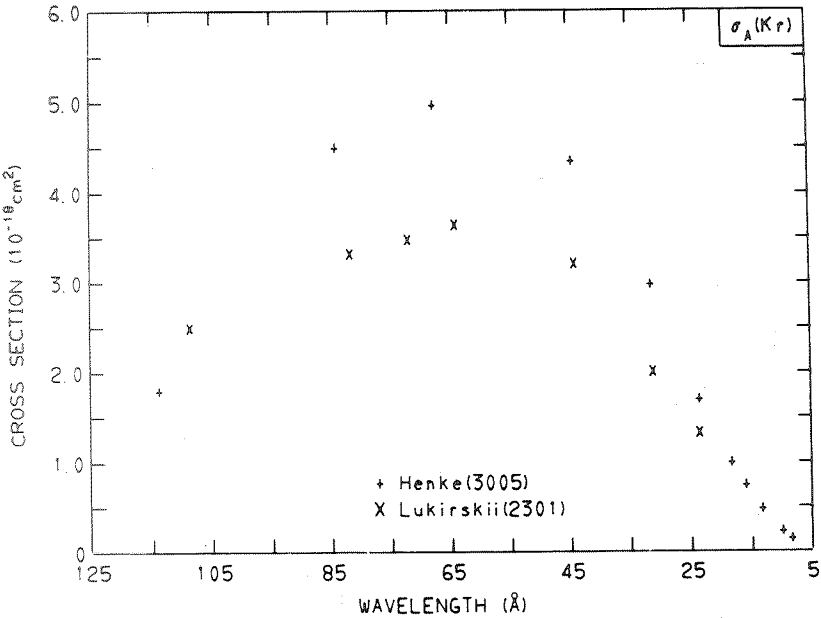

FIGURE 17 (concluded).—(*f*) 5 to 125 Å.

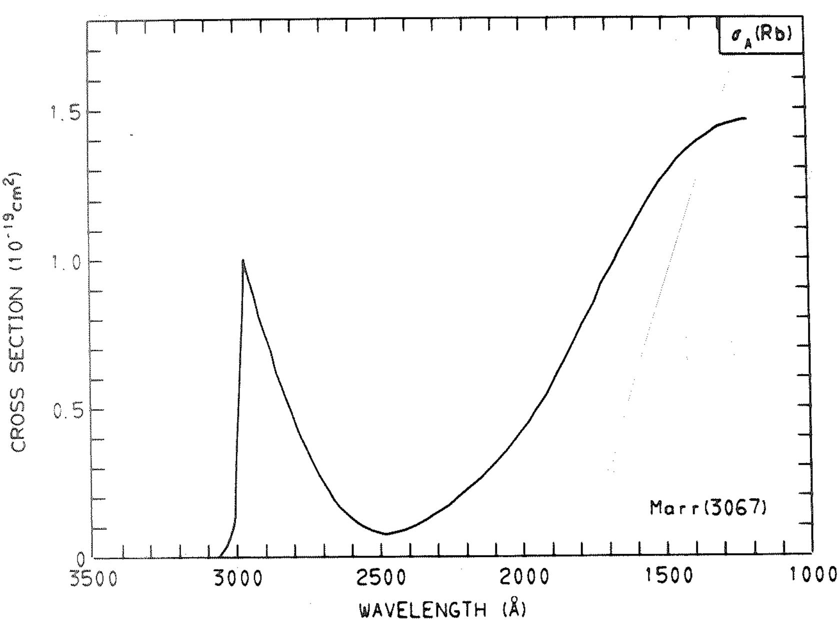

FIGURE 18.—Total absorption cross section of rubidium, 1000 to 3500 Å.

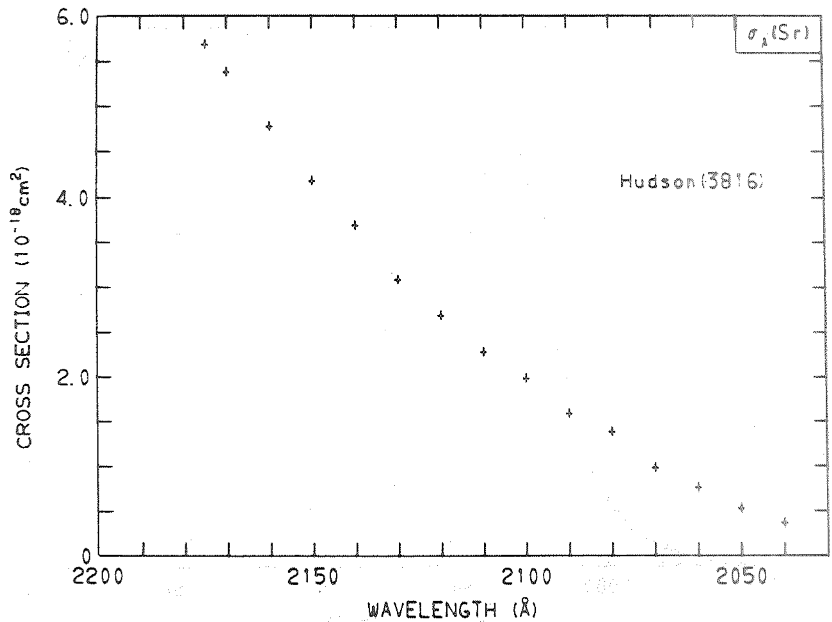

FIGURE 19.—Total absorption cross section of strontium. (*a*) 2030 to 2200 Å.

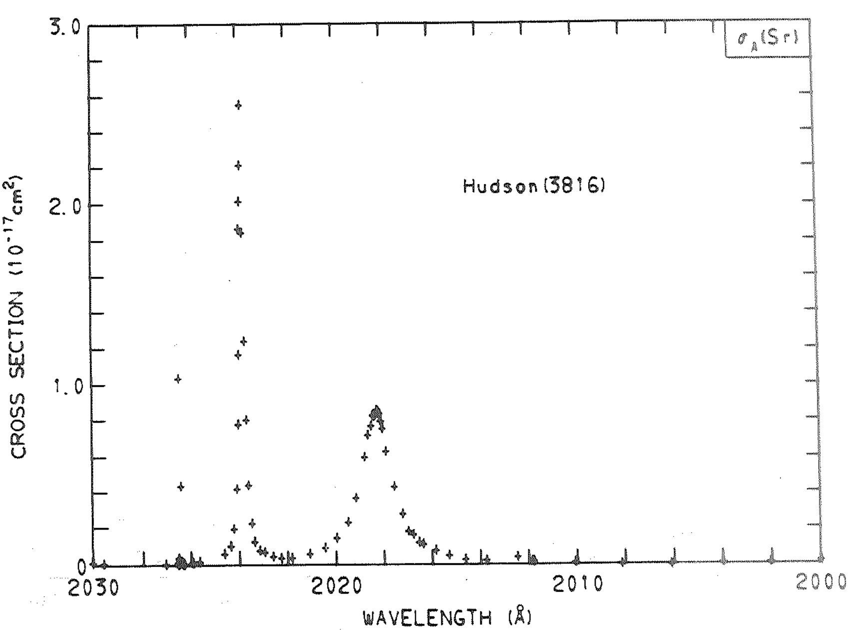

FIGURE 19 (continued).—(*b*) 2000 to 2030 Å.

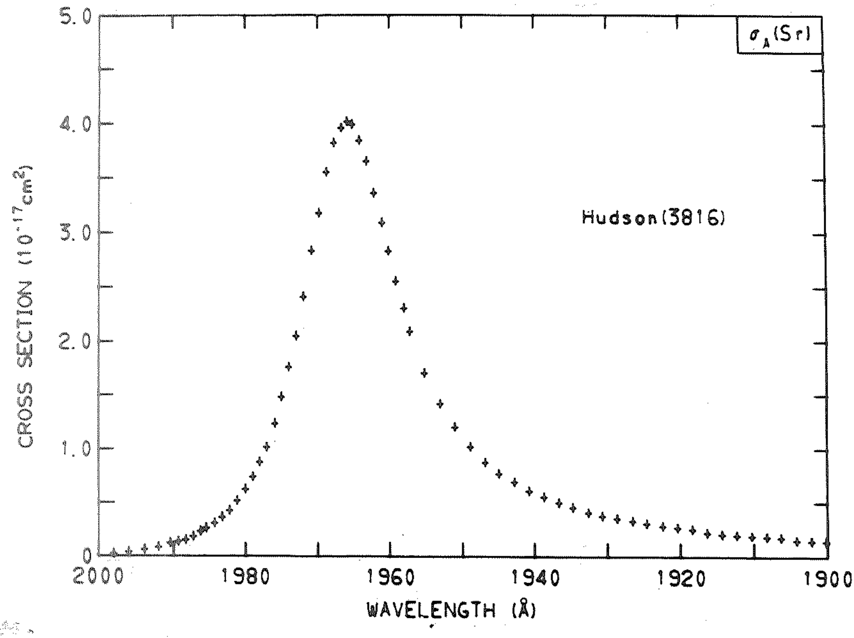

FIGURE 19 (continued).—(c) 1900 to 2000 Å.

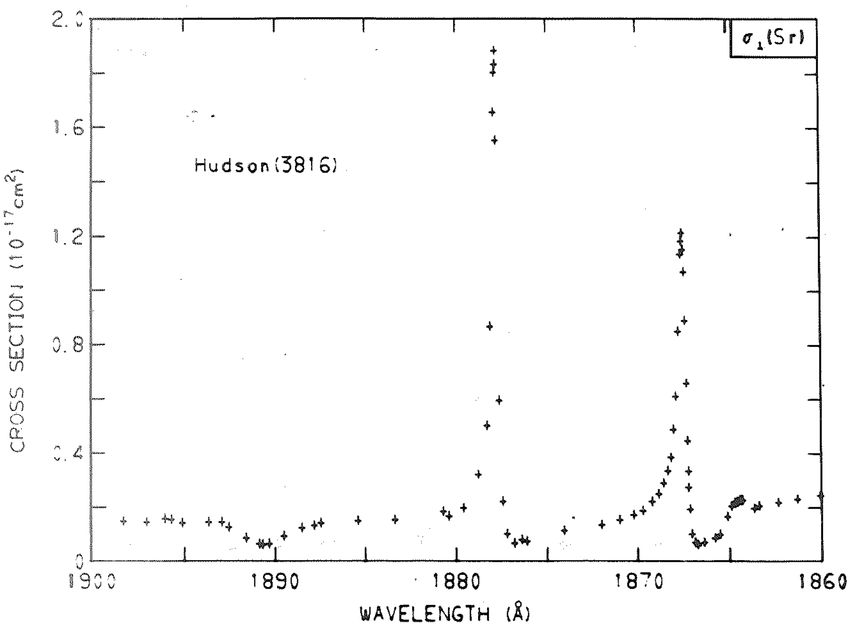

FIGURE 19 (continued).—(d) 1860 to 1900 Å.

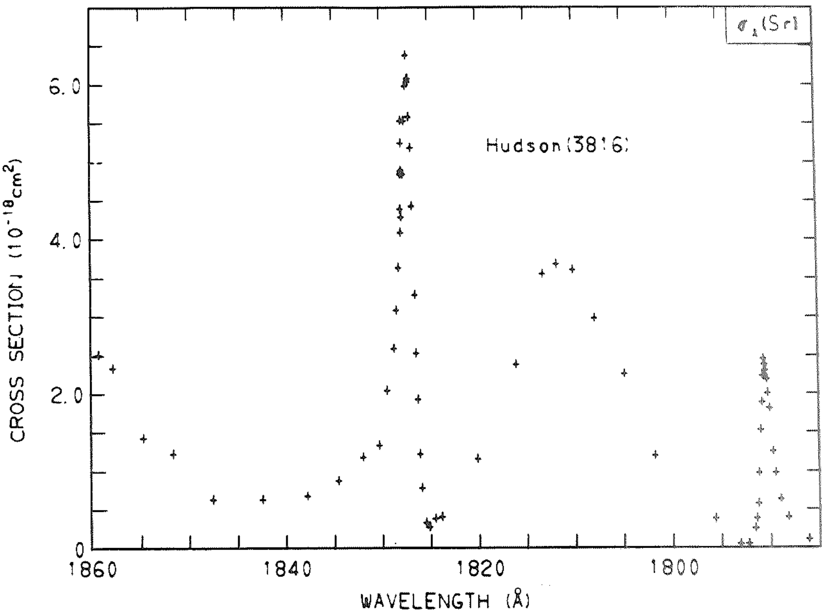

FIGURE 19 (continued).—(e) 1780 to 1860 Å.

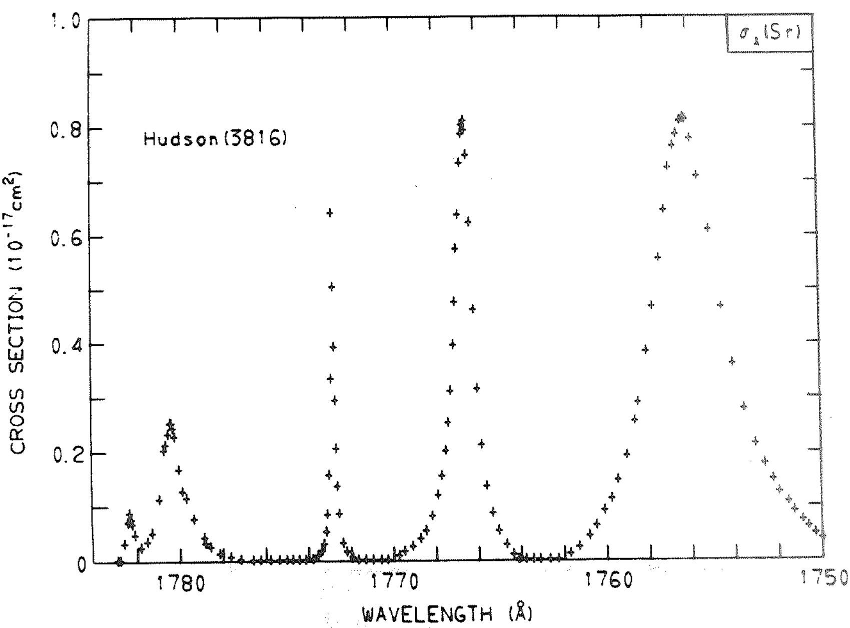

FIGURE 19 (continued).—(f) 1750 to 1784 Å.

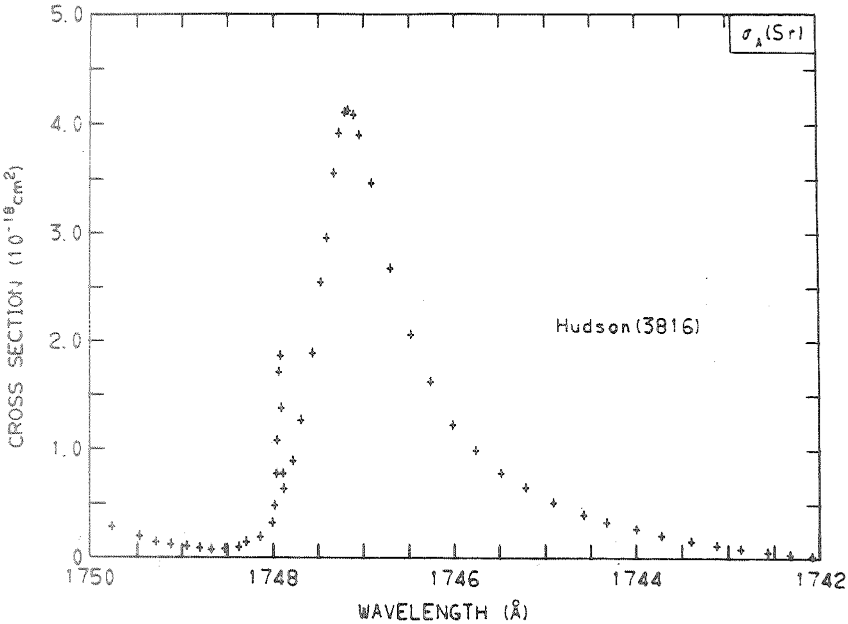

FIGURE 19 (continued).—(g) 1742 to 1750 Å.

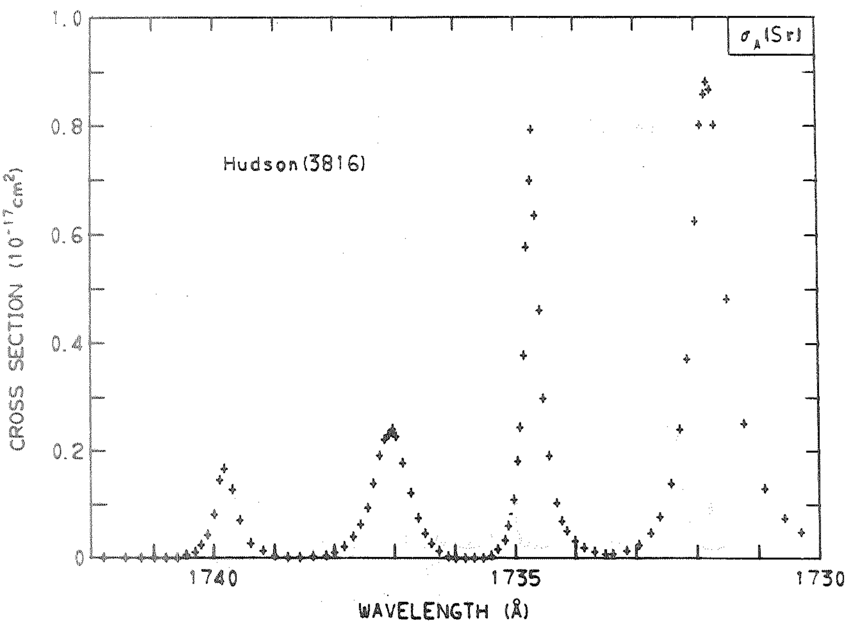

FIGURE 19 (continued).—(h) 1730 to 1742 Å.

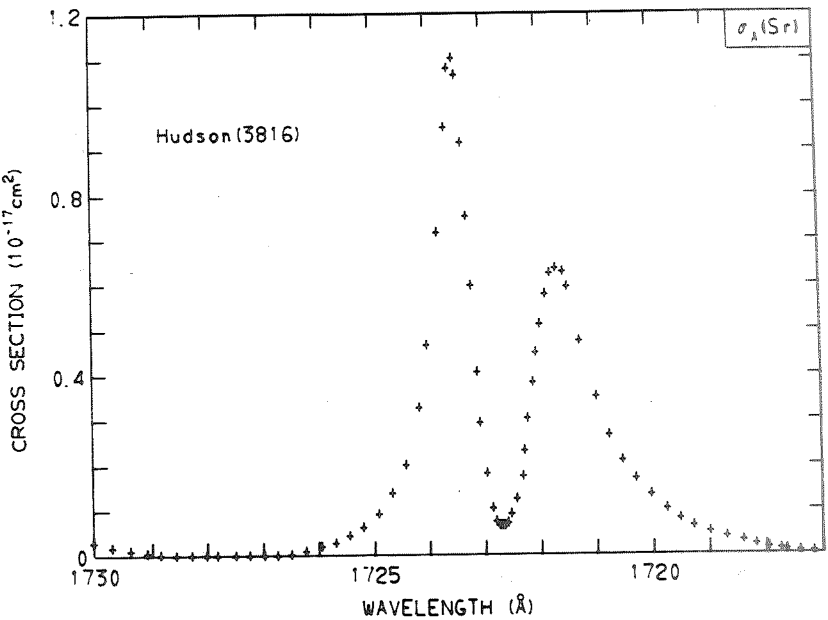

FIGURE 19 (continued).—(*i*) 1717 to 1730 Å.

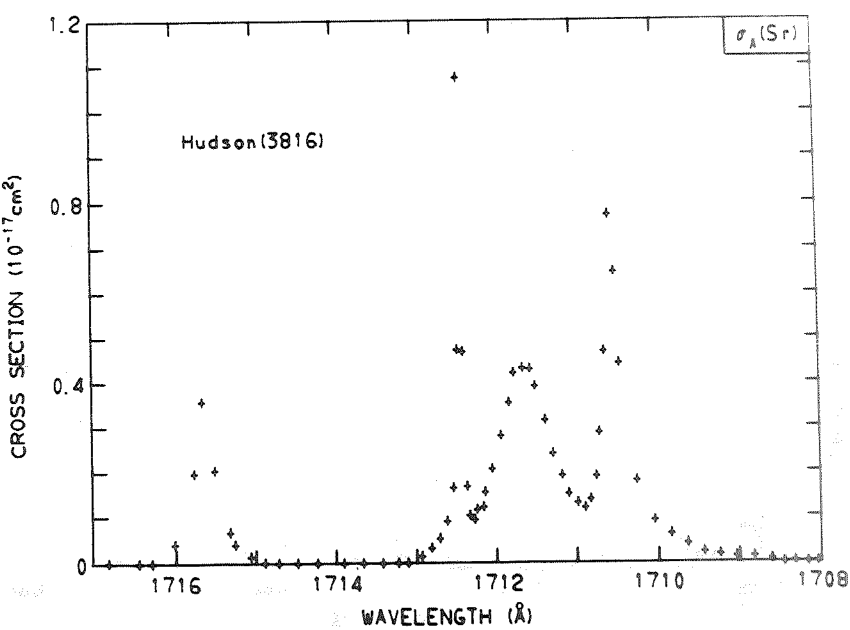

FIGURE 19 (continued).—(*j*) 1708 to 1717 Å.

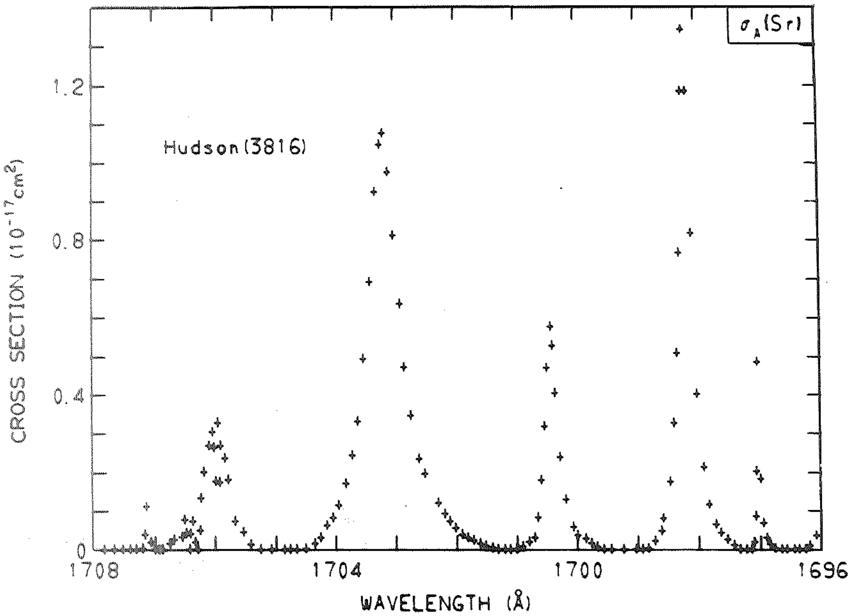

FIGURE 19 (continued).—(*k*) 1696 to 1708 Å.

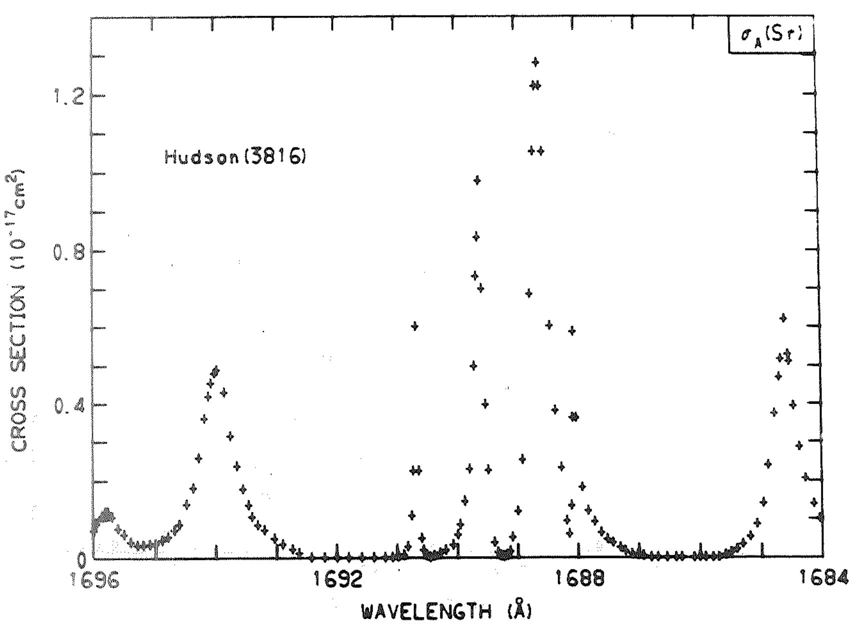

FIGURE 19 (continued).—(*l*) 1684 to 1696 Å.

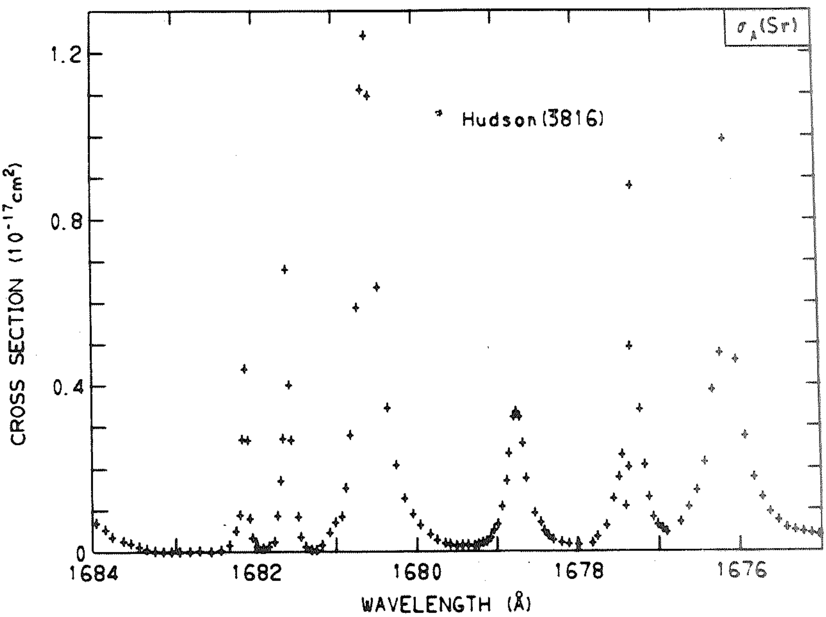

FIGURE 19 (continued).—(*m*) 1675 to 1684 Å.

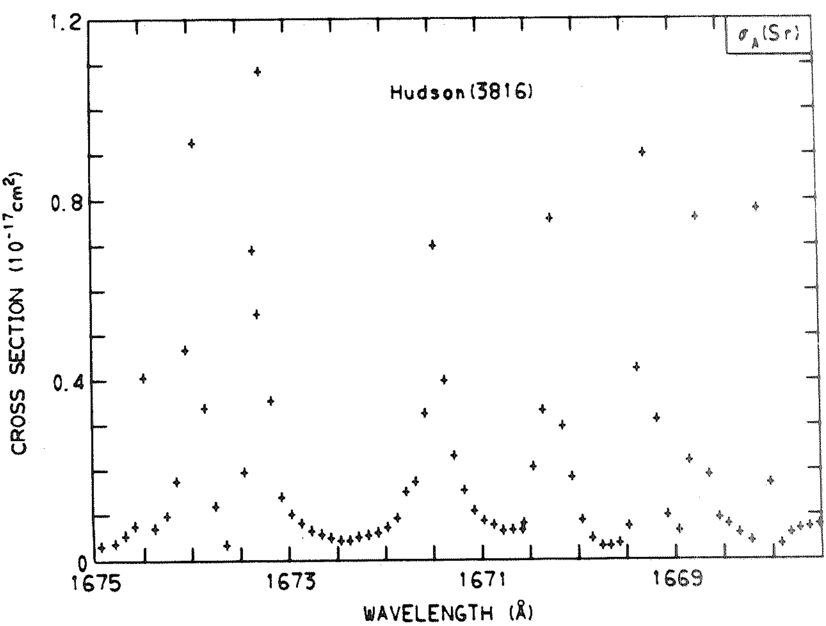

FIGURE 19 (continued).—(*n*) 1668 to 1675 Å.

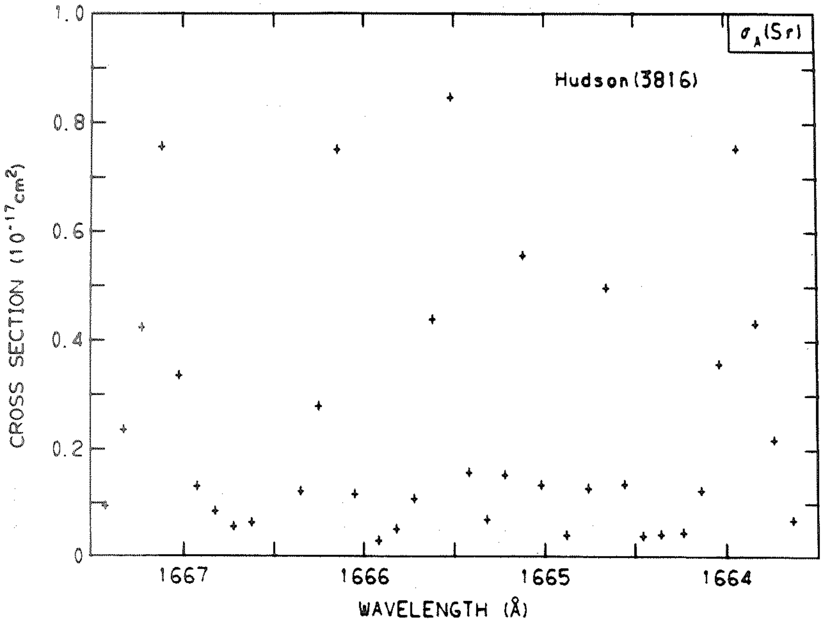

FIGURE 19 (continued).—(*o*) 1664 to 1667 Å.

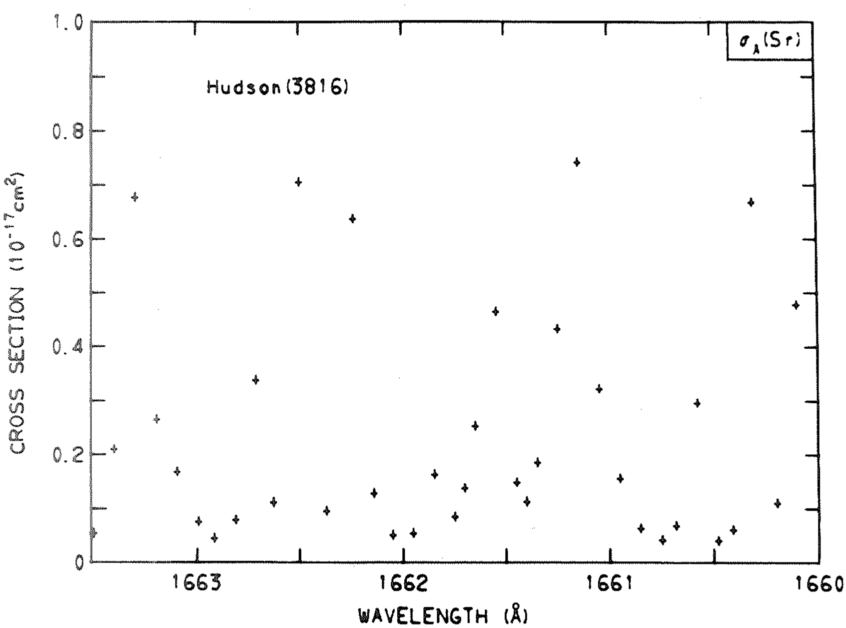

FIGURE 19 (continued).—(*p*) 1660 to 1663 Å.

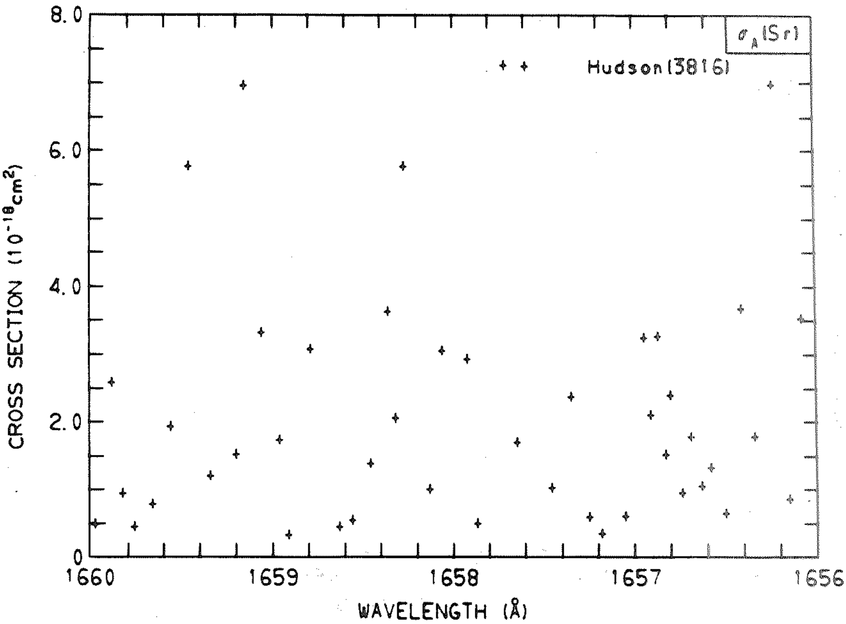

FIGURE 19 (continued).—(q) 1656 to 1660 Å.

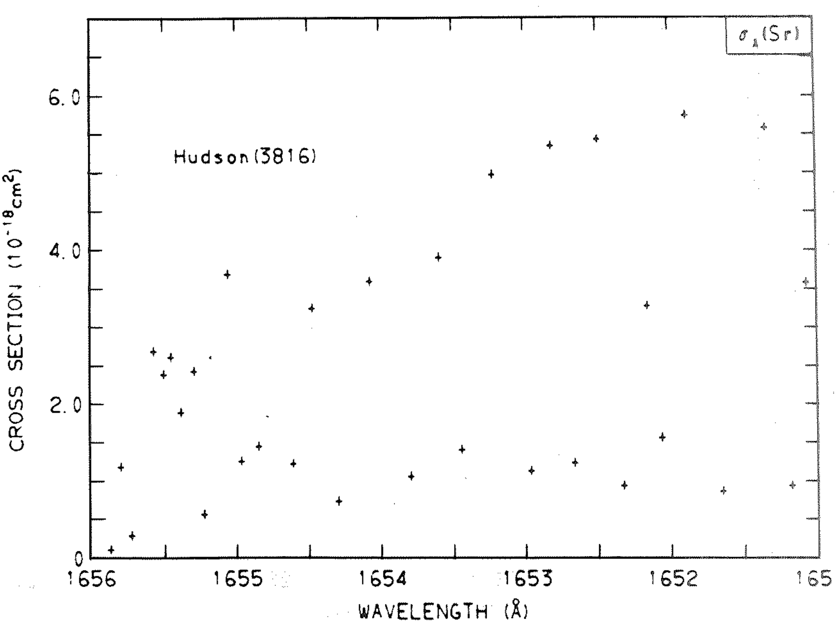

FIGURE 19 (continued).—(r) 1651 to 1656 Å.

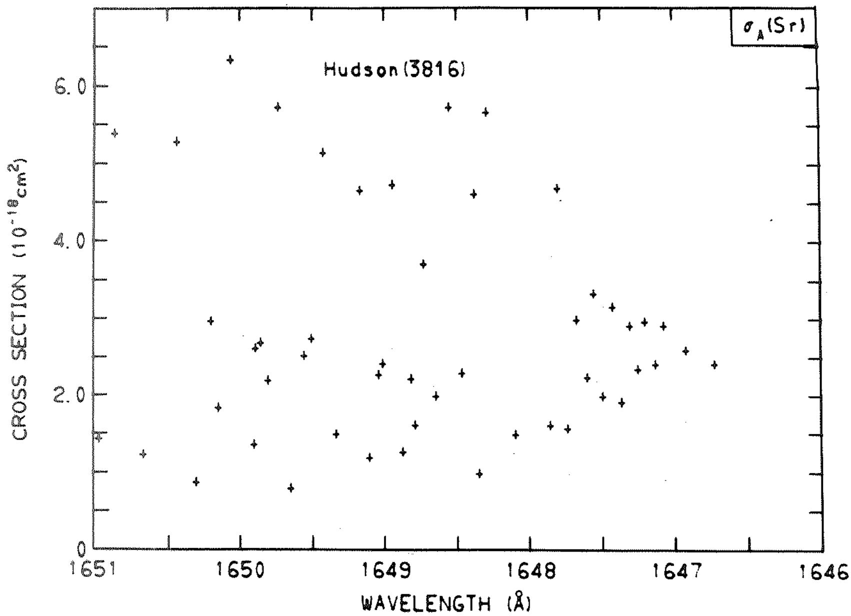

FIGURE 19 (concluded).—(*s*) 1646 to 1651 Å.

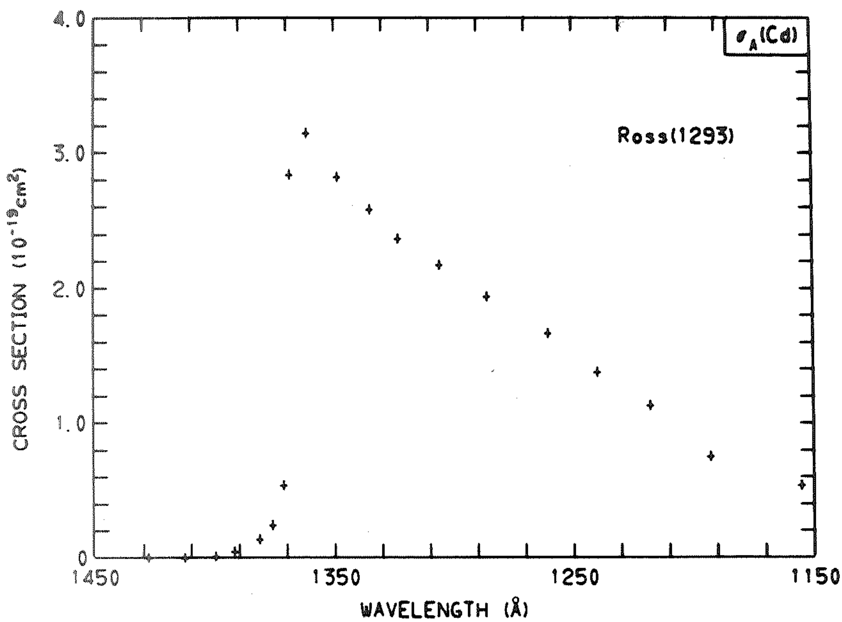

FIGURE 20.—Total absorption cross section of cadmium. (*a*) 1150 to 1450 Å.

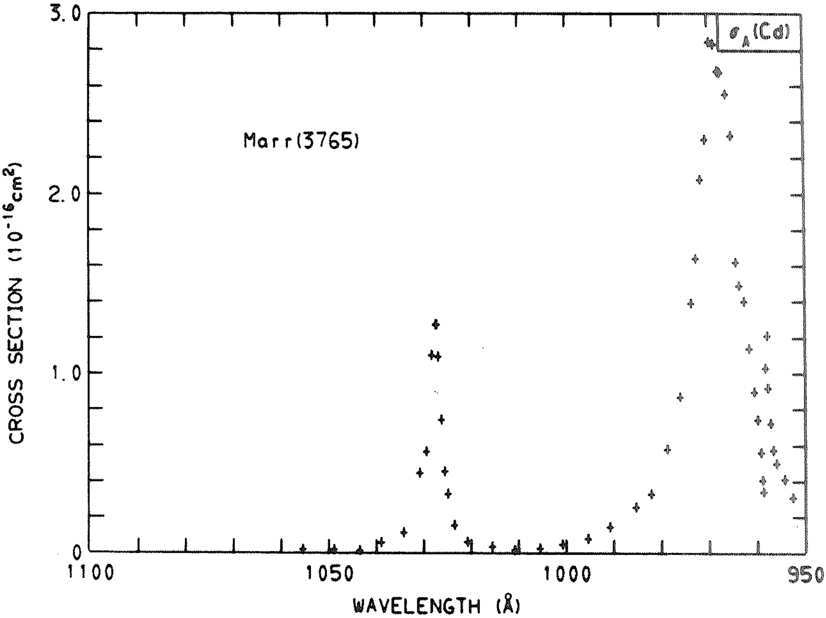

FIGURE 20 (continued).—(*b*) 950 to 1100 Å.

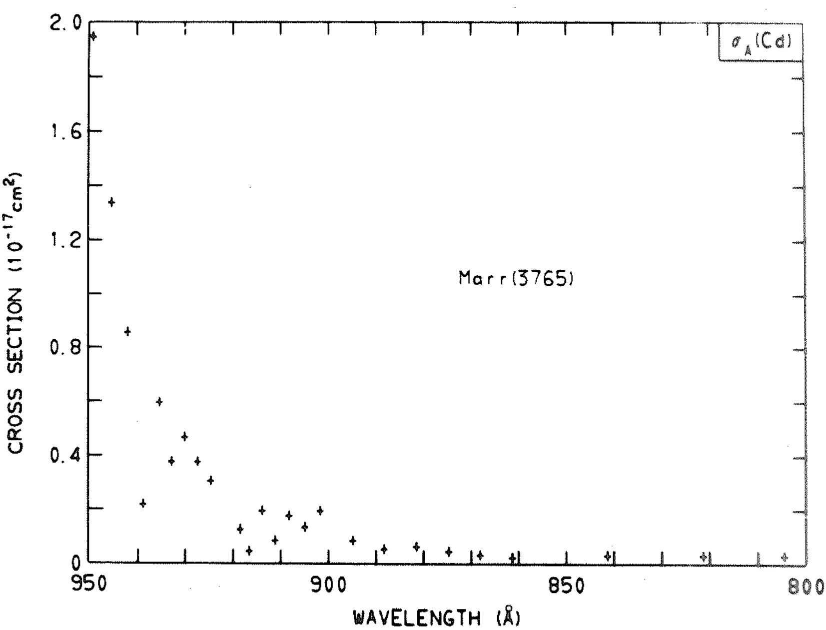

FIGURE 20 (continued).—(*c*) 800 to 950 Å.

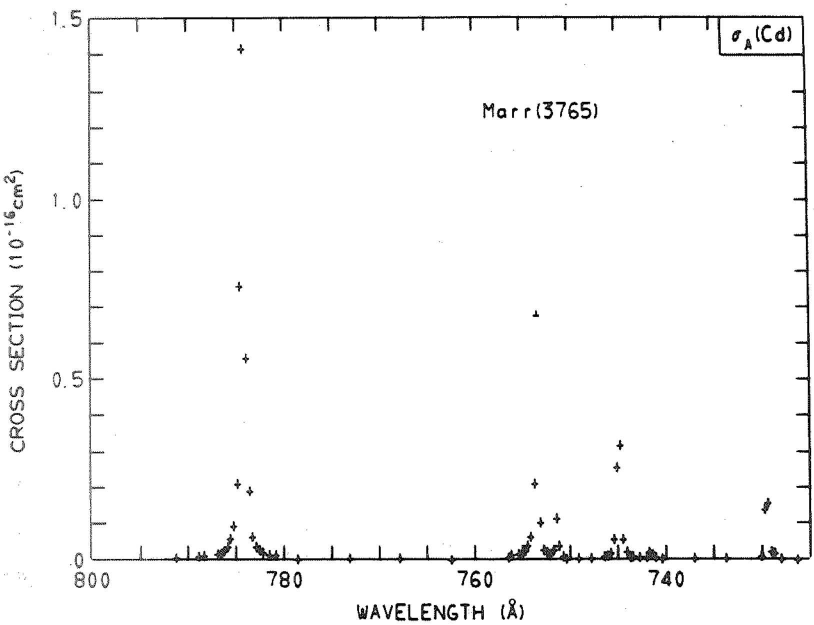

FIGURE 20 (continued).—(*d*) 725 to 800 Å.

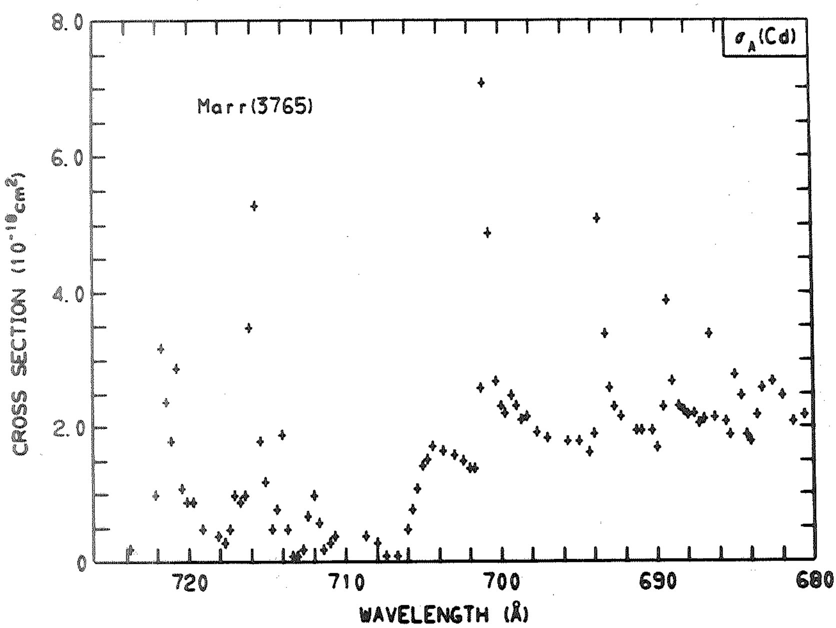

FIGURE 20 (continued).—(*e*) 680 to 726 Å.

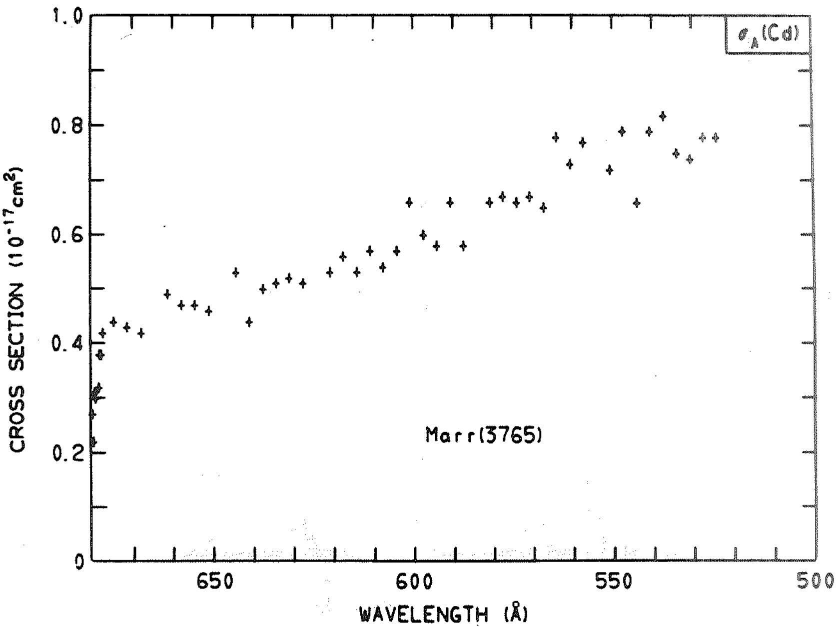

FIGURE 20 (concluded).—(f) 500 to 680 Å.

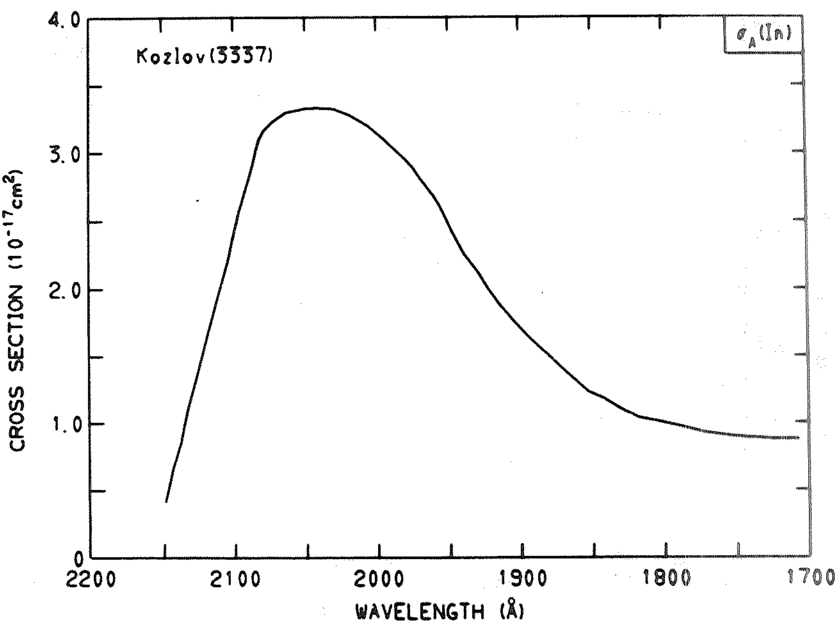

FIGURE 21.—Total absorption cross section of indium. (a) 1700 to 2200 Å.

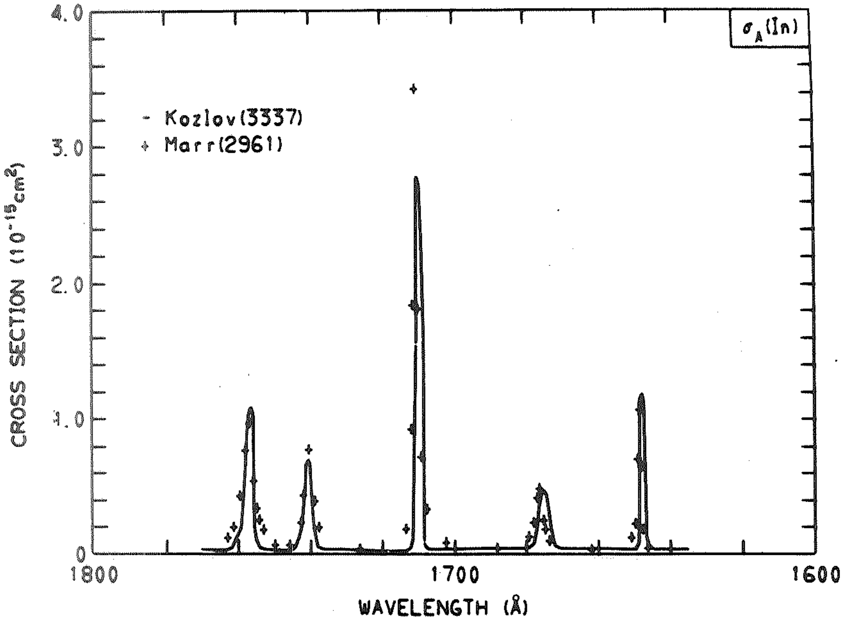

FIGURE 21 (concluded).—(*b*) 1600 to 1800 Å.

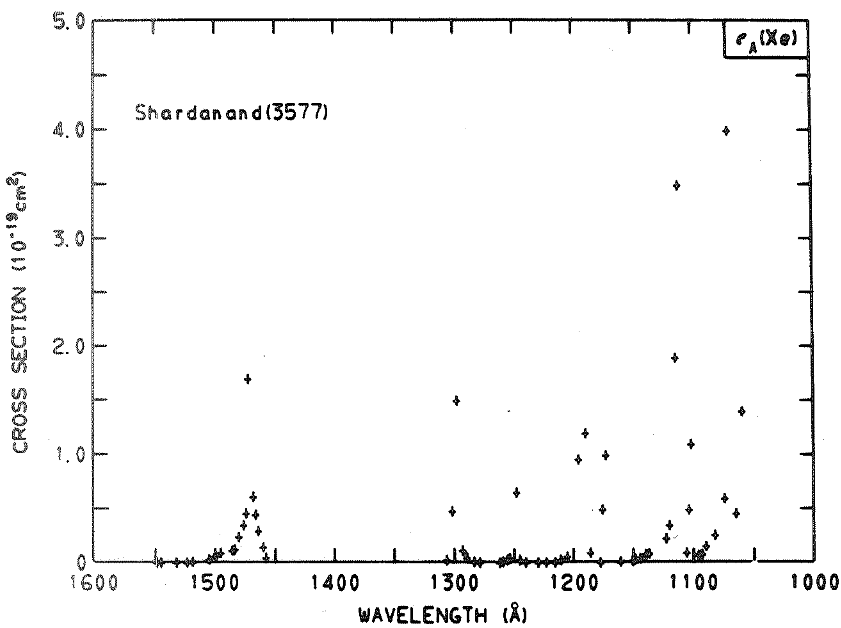

FIGURE 22.—Total absorption cross section of xenon. (*a*) 1000 to 1600 Å.

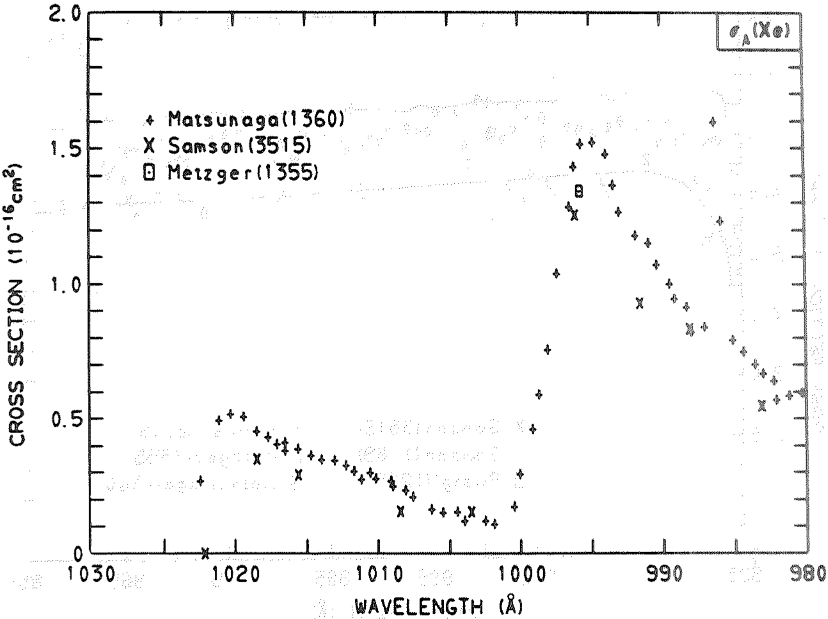

FIGURE 22 (continued).—(*b*) 980 to 1030 Å.

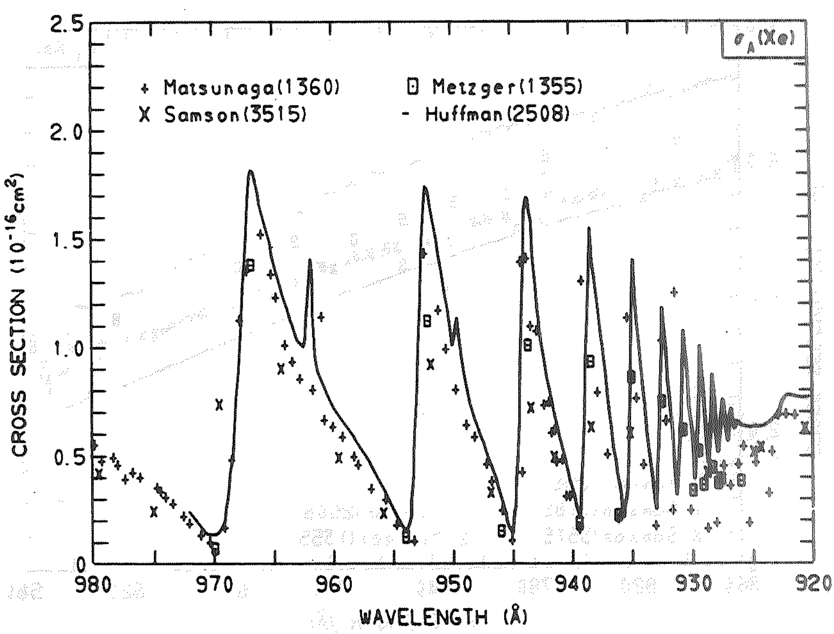

FIGURE 22 (continued).—(*c*) 920 to 980 Å.

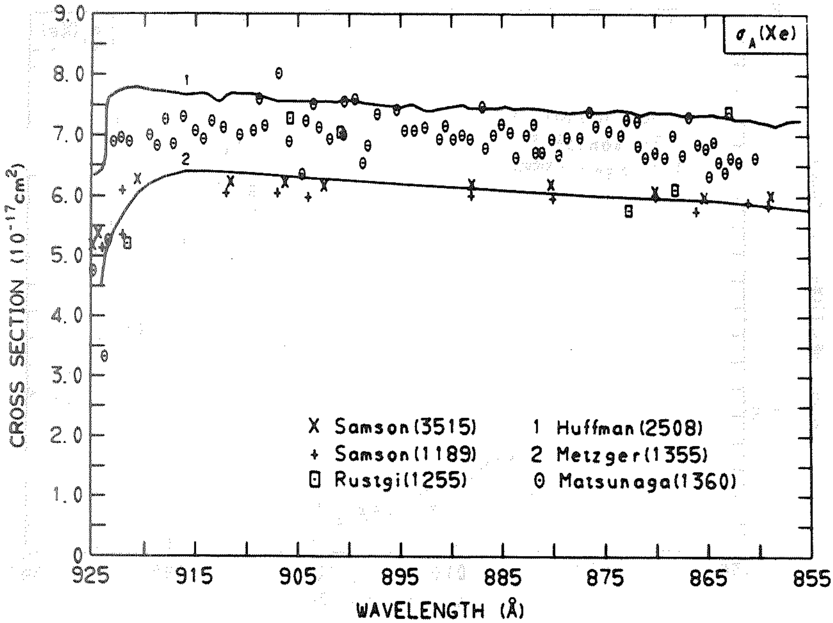

FIGURE 22 (continued).—(*d*) 855 to 925 Å.

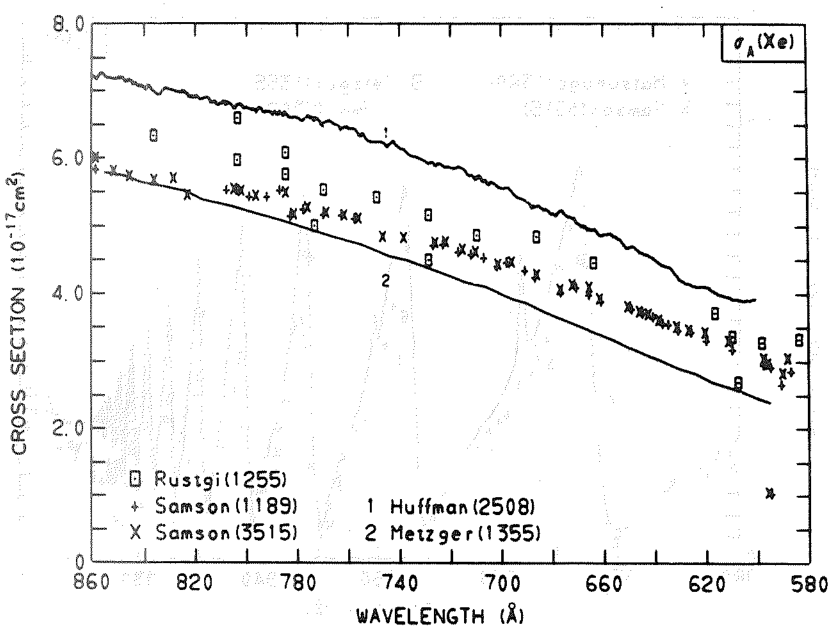

FIGURE 22 (continued).—(*e*) 580 to 860 Å.

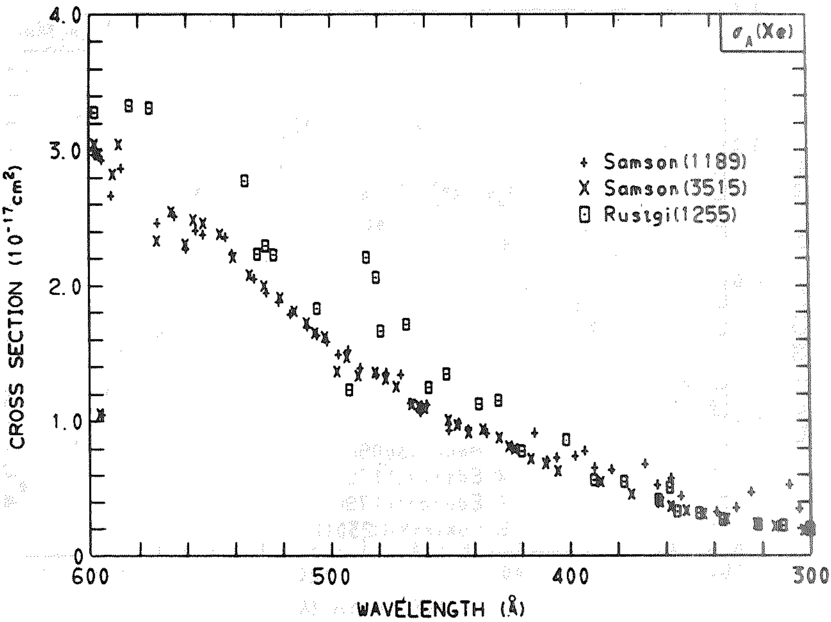

FIGURE 22 (continued).—(*f*) 300 to 600 Å.

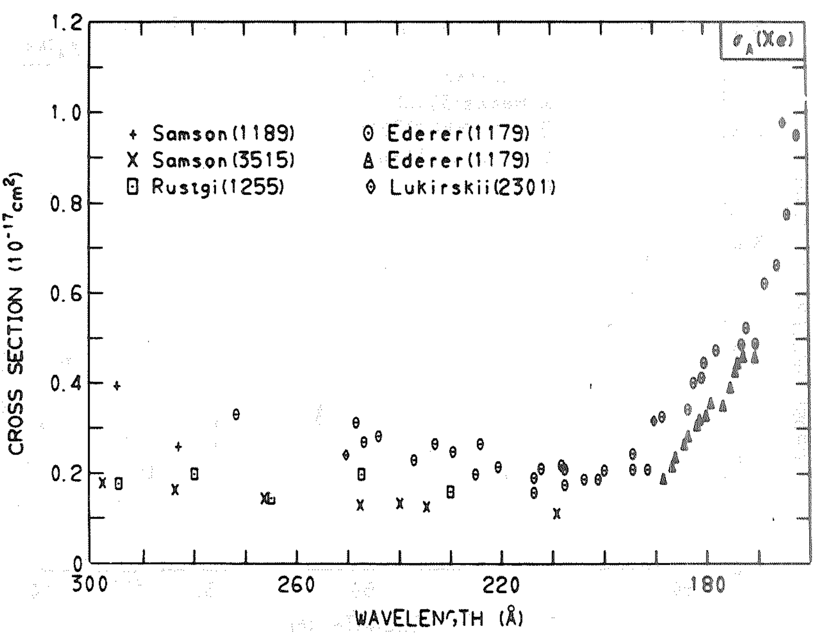

FIGURE 22 (continued).—(*g*) 160 to 300 Å.

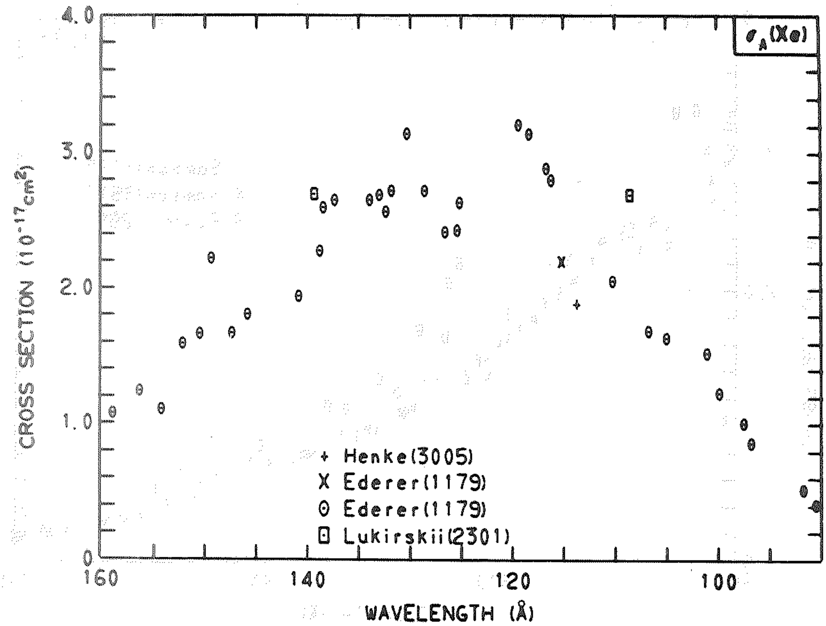

FIGURE 22 (continued).—(*h*) 90 to 160 Å.

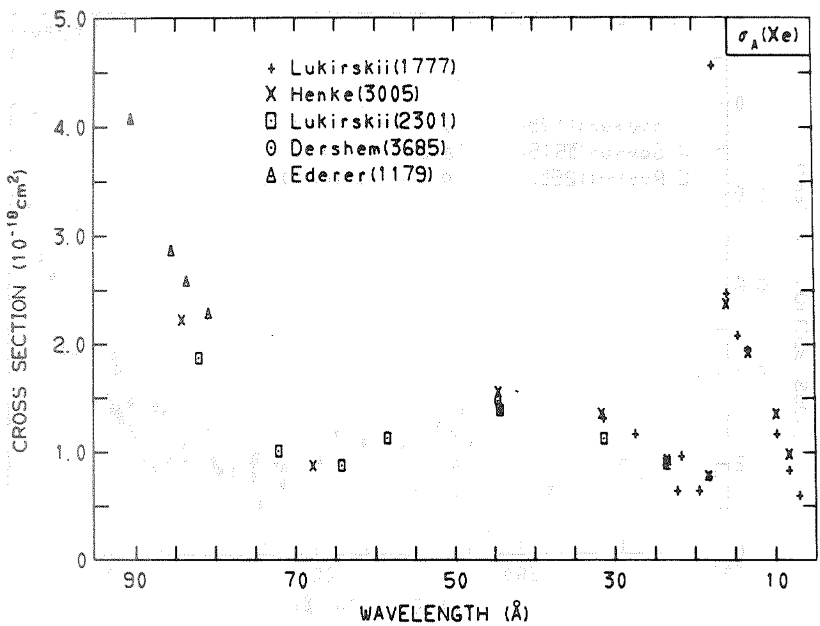

FIGURE 22 (continued).—(*i*) 5 to 95 Å.

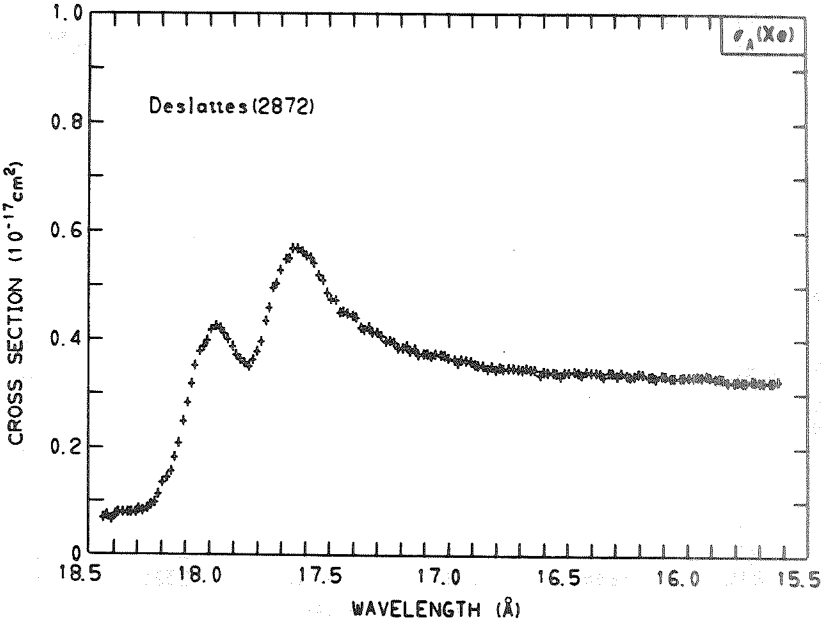

FIGURE 22 (concluded).—(j) 15.5 to 18.5 Å.

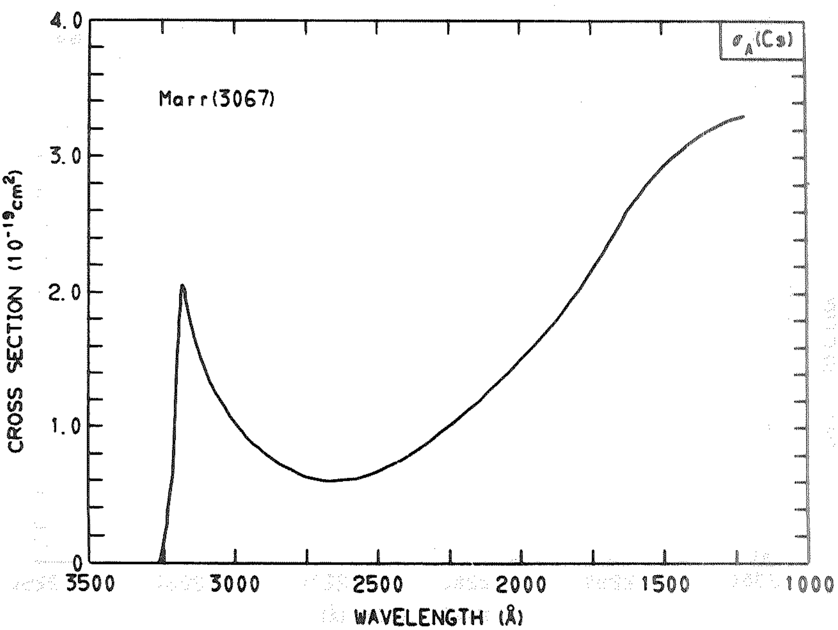

FIGURE 23.—Total absorption cross section of cesium, 1000 to 3500 Å.

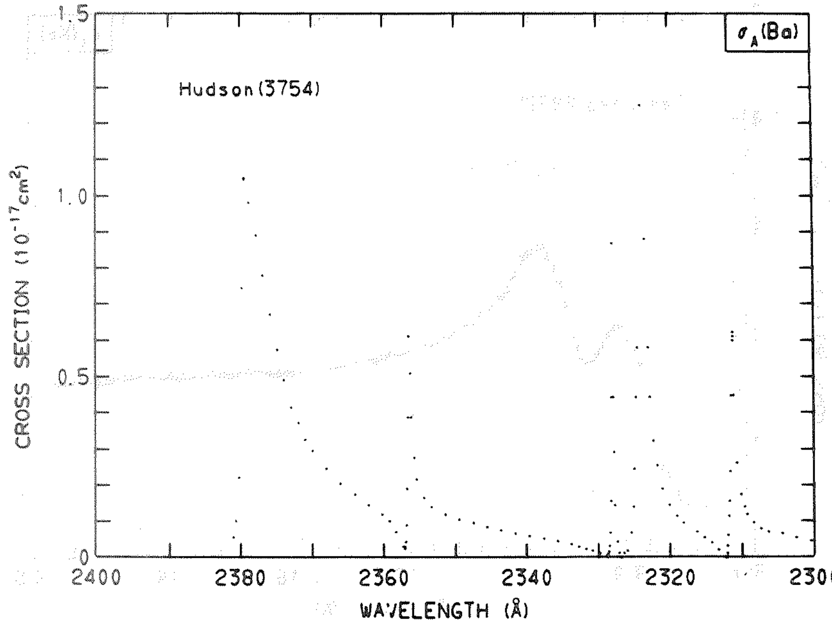

FIGURE 24.—Total absorption cross section of barium. (*a*) 2300 to 2400 Å.

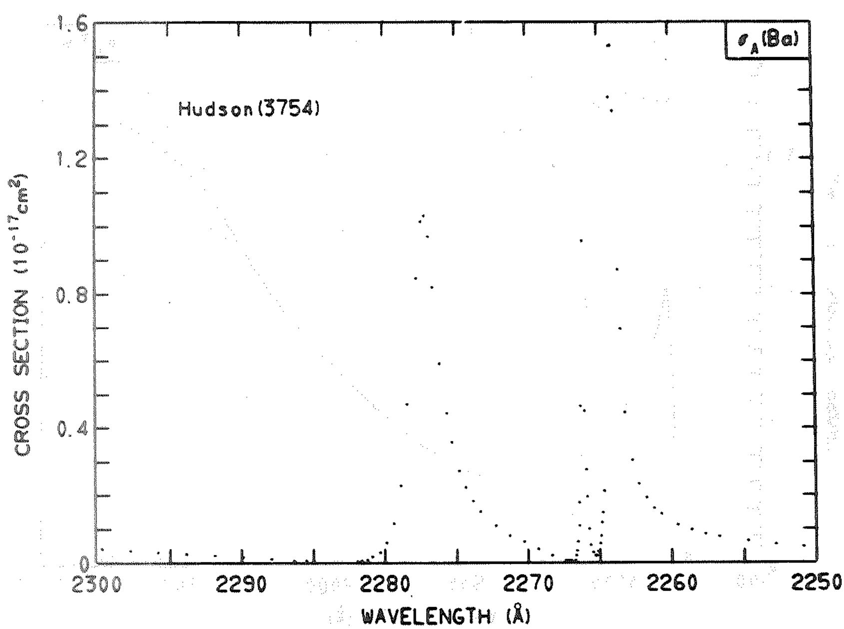

FIGURE 24 (continued).—(*b*) 2250 to 2300 Å.

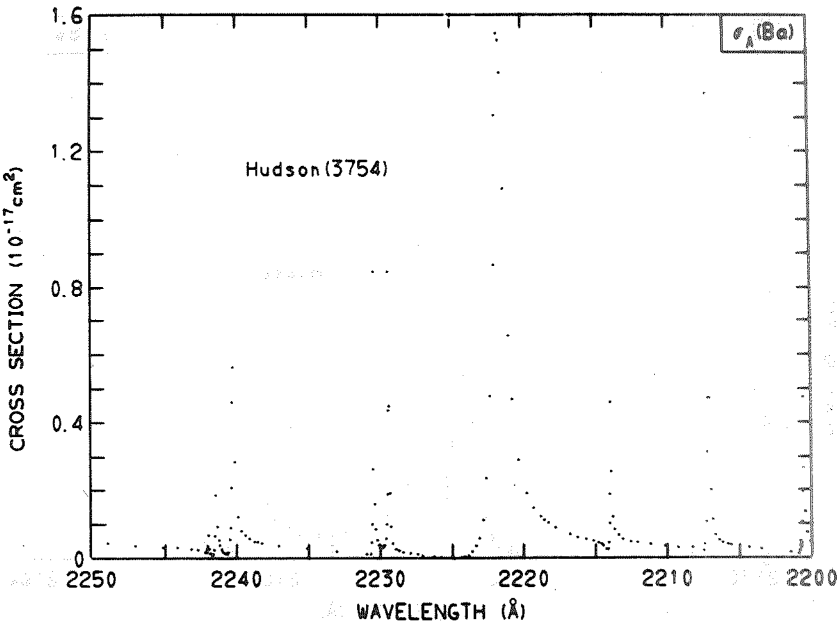

FIGURE 24 (continued).—(c) 2200 to 2250 Å.

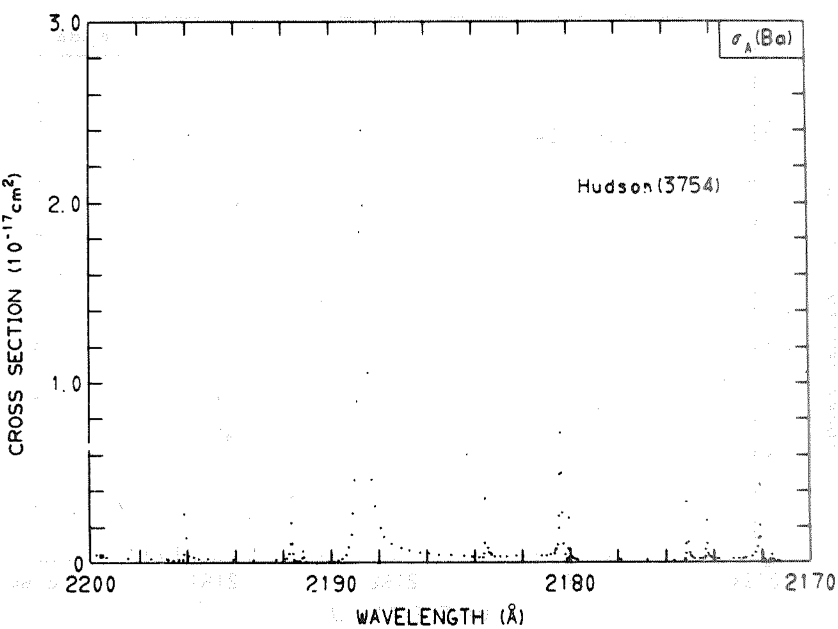

FIGURE 24 (continued).—(d) 2170 to 2200 Å.

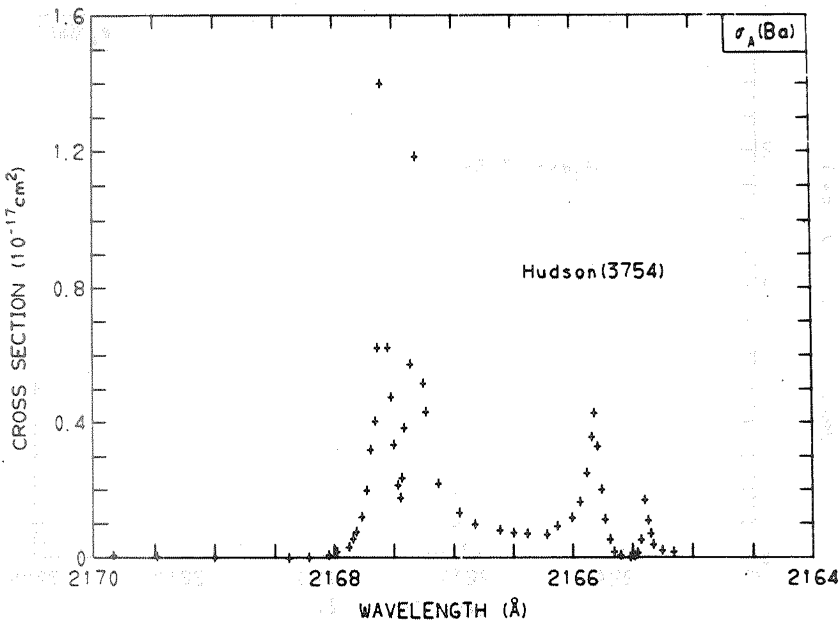

FIGURE 24 (continued).—(*e*) 2164 to 2170 Å.

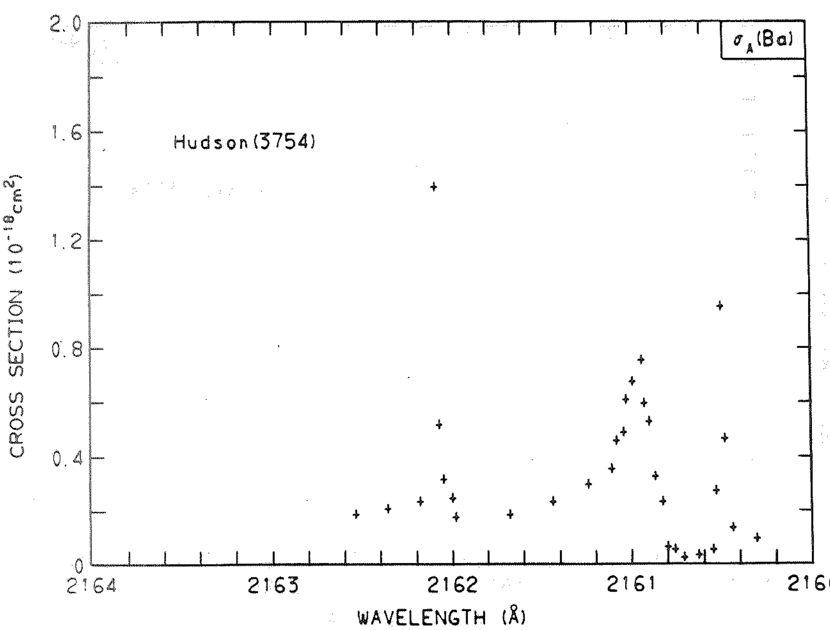

FIGURE 24 (continued).—(*f*) 2160 to 2164 Å.

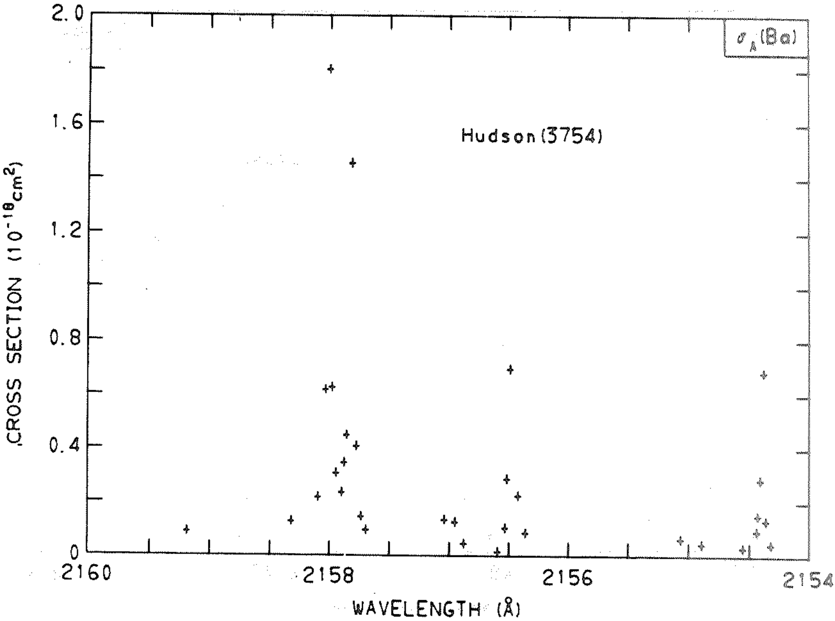

FIGURE 24 (continued).—(*g*) 2154 to 2160 Å.

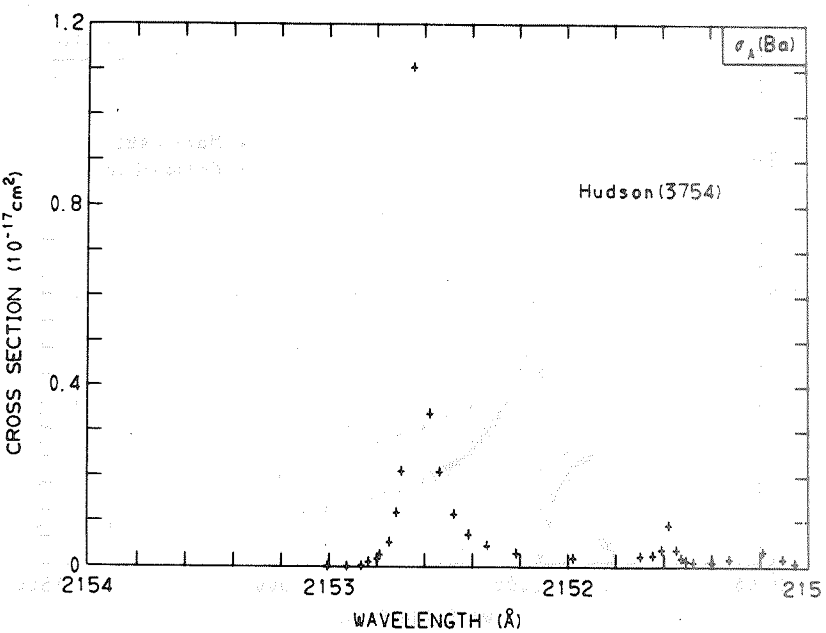

FIGURE 24 (continued).—(*h*) 2151 to 2154 Å.

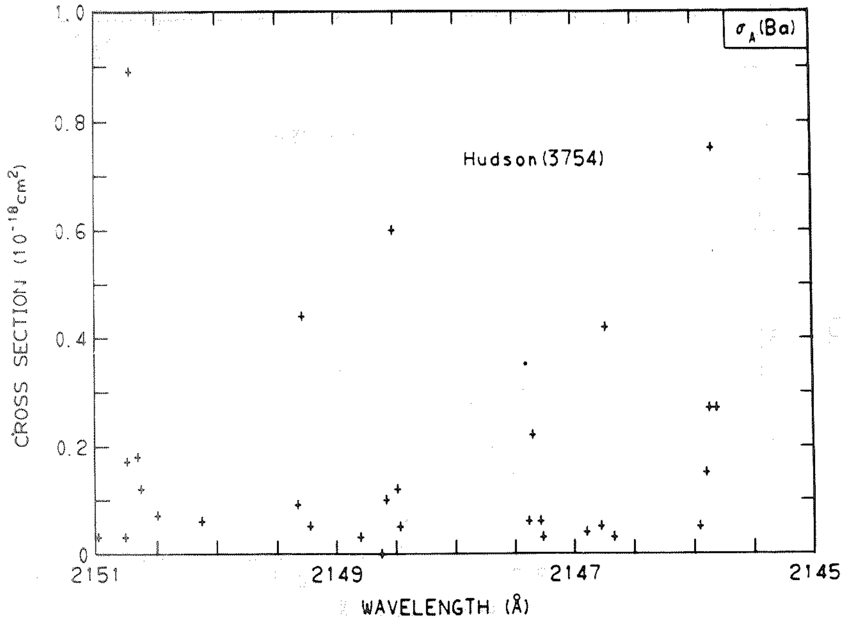

FIGURE 24 (concluded).—(*i*) 2145 to 2151 Å.

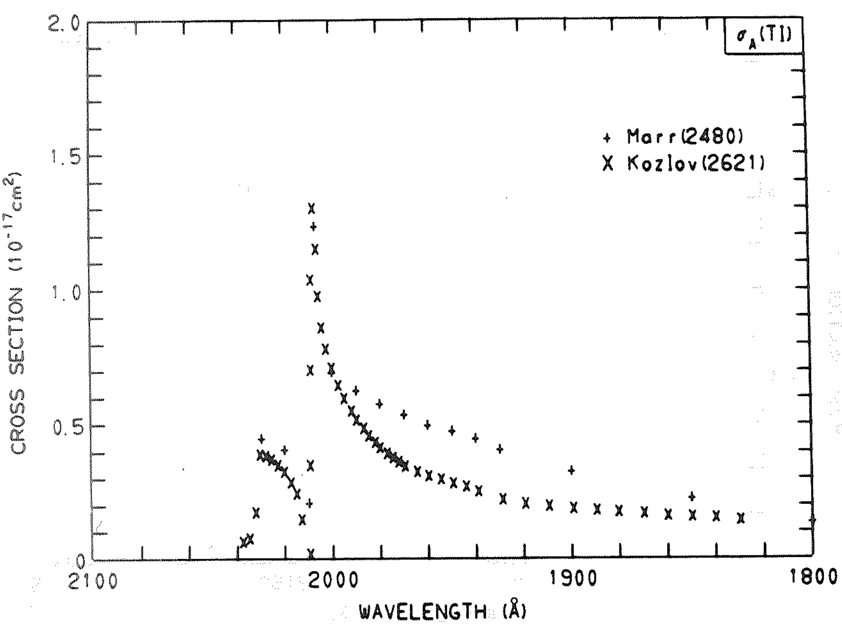

FIGURE 25.—Total absorption cross section of thallium. (*a*) 1800 to 2100 Å.

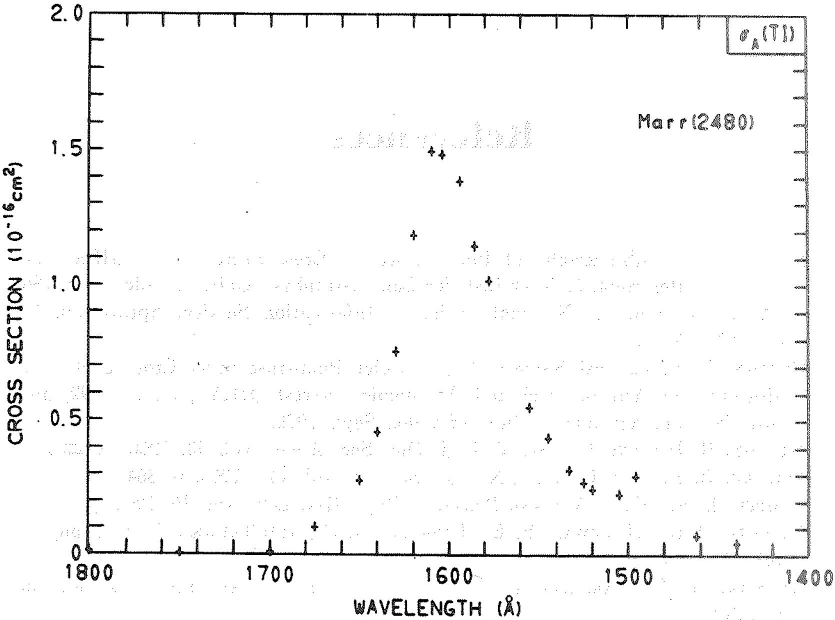

FIGURE 25 (concluded).—(*b*) 1400 to 1800 Å.

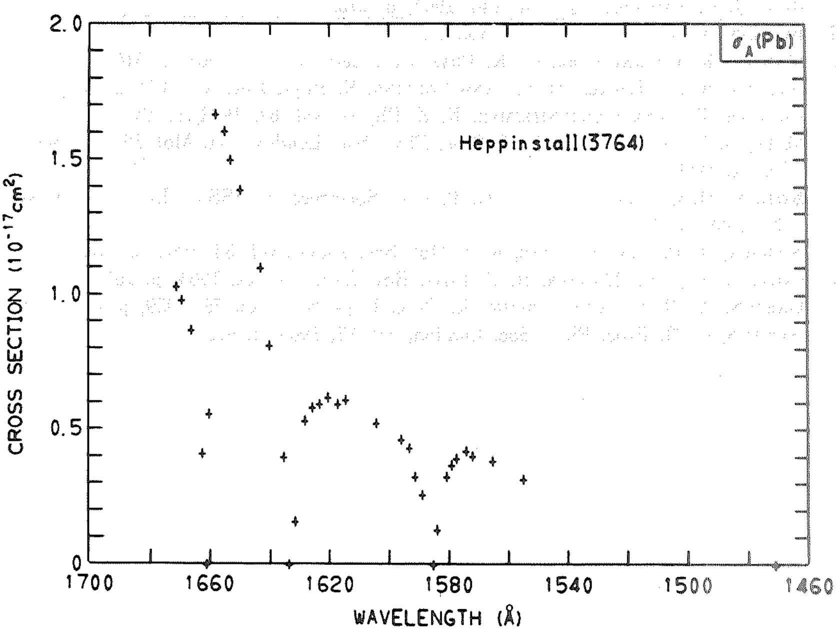

FIGURE 26.—Total absorption cross section of lead, 1460 to 1700 Å.

References

1. KIEFFER, L. J. Bibliography of Photoabsorption Cross Section Data. JILA Information Center Rept. 5, Joint Inst. for Lab. Astrophys., Univ. of Colo., Apr. 1968. (Available from the National Technical Information Service, Springfield, Va., no. PB 189 132.)
2. HUDSON, R. D. Critical Review of Ultraviolet Photoabsorption Cross Section for Molecules of Astrophysical and Aeronomic Interest. JILA pub. no. 692, Joint Inst. for Lab. Astrophys., Univ. of Colo., Sept. 1970.
3. HUDSON, R. D.; AND CARTER, V. L. J. Opt. Soc. Amer., vol. 58, 1968, p. 227.
4. MADDEN, R. P.; AND CODLING, K. Astrophys. J., vol. 141, 1965, p. 364.
5. COOPER, J. W.; FANO, V.; AND PRATS, F. Phys. Rev. Lett., vol. 10, 1963, p. 518.
6. CARROLL, P. K.; HUFFMAN, R. E.; LARRABEE, J. C.; AND TANAKA, Y. Astrophys. J., vol. 146, 1966, p. 553.
7. HUFFMAN, R. E.; LARRABEE, J. C.; AND TANAKA, Y. J. Chem. Phys., vol. 46, 1967, p. 2213.
8. CODLING, K.; MADDEN, R. P.; AND EDERER, D. L. Phys. Rev., vol. 155, 1967, p. 26.
9. KOZLOV, M. G.; NIKONOVA, E. I.; AND STARTSEV, G. P. Opt. Spectrosc. (USSR) (Eng. trans.), vol. 21, 1966, p. 298.
10. RICH, J. C. Astrophys. J., vol. 148, 1967, p. 275.
11. BEUTLER, H. Z. Physik, vol. 93, 1935, p. 177.
12. MADDEN, R. P.; AND CODLING, K. Phys. Rev. Lett., vol. 10, 1963, p. 516.
13. MADDEN, R. P.; EDERER, D. L.; AND CODLING, K. Phys. Rev., vol. 177, 1969, p. 136.
14. BEUTLER, H.; AND GUGGENHEIMER, K. Z. Physik, vol. 87, 1933, p. 188.
15. MARR, G. V.; AND AUSTIN, J. M. Proc. Phys. Soc. London (At. Mol. Phys.), Ser. 2, vol. 2, 1969, p. 107.
16. KOZLOV, M. G.; AND STARTSEV, G. P. Opt. Spectrosc. (USSR) (Eng. trans.), vol. 24, 1968, p. 3.
17. MADDEN, R. P.; AND CODLING, K. J. Opt. Soc. Amer., vol. 54, 1964, p. 268.
18. CODLING, K.; AND MADDEN, R. P. Phys. Rev. Lett., vol. 12, 1964, p. 106.
19. GARTON, W. R. S.; AND CODLING, K. Proc. Phys. Soc., vol. 75, 1959, p. 87.
20. NEWSON, G. H. Proc. Phys. Soc. London, vol. 87, 1966, p. 975.

Bibliography

575 Samson, J. A. R. Phys. Rev., vol. 132, 1963, p. 2122.

647 Baker, D. J.; Bedo, D. E.; and Tomboulian, D. H. Phys. Rev., vol. 124, 1961, p. 1471.

926 Comes, F. J.; and Elzer, A. Z. Naturforsch., vol. 19A, 1964, p. 721.

993 Samson, J. A. R. J. Opt. Soc. Amer., vol. 54, 1964, p. 420.

1179 Ederer, D. L. Phys. Rev. Lett., vol. 13, 1964, p. 760.

1188 Samson, J. A. R. J. Opt. Soc. Amer., vol. 54, 1964, p. 876.

1189 Samson, J. A. R. J. Opt. Soc. Amer., vol. 54, 1964, p. 842.

1255 Rustgi, O. P.; Fisher, E. I.; and Fuller, C. H. J. Opt. Soc. Amer., vol. 54, 1964, p. 745.

1293 Ross, K. J.; and Marr, G. V. Proc. Phys. Soc. London, vol. 85, 1965, p. 193.

1350 Lowry, J. F.; Tomboulian, D. H.; and Ederer, D. L. Phys. Rev., vol. 137, 1965, p. A1054.

1351 Madden, R. P.; and Codling, K. Astrophys. J., vol. 141, 1965, p. 364.

1353 Hudson, R. D.; and Carter, V. L. Phys. Rev., vol. 137, 1965, p. A1648.

1355 Metzger, P. H.; and Cook, G. R. J. Opt. Soc. Amer., vol. 55, 1965, p. 516.

1359 Cairns, R. B.; and Samson, J. A. R. J. Geophys. Res., vol. 70, 1965, p. 99.

1360 Matsunaga, F. M.; Watanabe, K.; and Jackson, R. S. J. Quant. Spectrosc. Radiat. Transfer, vol. 5, 1965, p. 329.

1405 Hudson, R. D.; and Carter, V. L. Phys. Rev., vol. 139, 1965, p. A1426.

1562 Samson, J. A. R. J. Opt. Soc. Amer., vol. 55, 1965, p. 935.

1739 Ditchburn, R. W.; Jutsum, P. J.; and Marr, G. V. Proc. Roy. Soc. London, vol. A219, 1953, p. 89.

1740 Ditchburn, R. W.; and Marr, G. V. Proc. Phys. Soc. London, vol. A66, 1953, p. 655.

1755 Ederer, D. L.; and Tomboulian, D. H. Phys. Rev., vol. 133, 1964, p. A1525.

1777 Lukirskii, A. P.; Brytov, I. A.; and Gribovskii, S. A. Opt. Spectrosc. (USSR) (Eng. trans.), vol. 20, 1966, p. 203.

2301 Lukirskii, A. P.; Brytov, I. A.; and Zimkina, T. M. Opt. Spectrosc. (USSR) (Eng. trans.), vol. 17, 1964, p. 234.

2380 Rich, J. C. Astrophys. J., vol. 148, 1967, p. 275.

2480 Marr, G. V. Proc. Roy. Soc. London, vol. A224, 1954, p. 83.

2507 Huffman, R. E.; Tanaka, Y.; and Larrabee, J. C. Appl. Opt., vol. 2, 1963, p. 947.

2508 Huffman, R. E.; Tanaka, Y.; and Larrabee, J. C. J. Chem. Phys., vol. 39, 1963, p. 902.

2552 Marr, G. V. Proc. Phys. Soc. London, vol. 81, 1963, p. 9.

2619 Hudson, R. D.; and Carter, V. L. J. Opt. Soc. Amer., vol. 57, 1967, p. 651.

2621 Kozlov, M. G.; Nikonova, E. I.; and Startsev, G. P. Opt. Spectrosc. (USSR) (Eng. trans.), vol. 21, 1966, p. 298.

2697 HUDSON, R. D.; AND CARTER, V. L. Astrophys. J., vol. 149, 1967, p. 229.
2703 LUKIRSKII, A. P.; AND ZIMKINA, T. M. Bull. Acad. Sci. USSR Phys. Ser. (Eng. trans.), vol. 27, 1963, p. 808.
2862 HUDSON, R. D.; AND CARTER, V. L. J. Opt. Soc. Amer., vol. 57, 1967, p. 1471.
2872 DESLATTES, R. D. Phys. Rev. Lett., vol. 20, 1968, p. 483.
2942 COMES, F. J.; AND ELZER, A. Z. Naturforsch., vol. 23A, 1968, p. 133.
2943 COMES, F. J.; SPEIER, F.; AND ELZER, A. Z. Naturforsch., vol. 23A, 1968, p. 125.
2961 MARR, G. V.; AND HEPPINSTALL, R. Proc. Phys. Soc. London, vol. 87, 1966, p. 547.
2973 HUDSON, R. D.; AND CARTER, V. L. J. Opt. Soc. Amer., vol. 58, 1968, p. 227.
3004 HUDSON, R. D.; AND CARTER, V. L. J. Opt. Soc. Amer., vol. 58, 1968, p. 430.
3005 HENKE, B. L.; ELGIN, R. L.; LENT, R. E.; AND LEDINGHAM, R. B. Norelco Reptr., vol. 14, 1967, p. 112.
3067 MARR, G. V.; AND CREEK, D. M. Proc. Roy. Soc. London, vol. A304, 1968, p. 233.
3253 HENKE, B. L.; ELGIN, R. L.; LENT, R. E.; AND LEDINGHAM, R. B. Rept. (AFOSR 67-1254, AD 654315), Pomona College (Claremont, Calif.), 1967.
3337 KOZLOV, M. G.; AND STARTSEV, G. P. Opt. Spectrosc. (USSR) (Eng. trans.), vol. 24, 1968, p. 3.
3515 SAMSON, J. A. R. Advances in Atomic and Molecular Physics, vol. II, 1966, pp. 177–261.
3577 SHARDANAND. J. Quant. Spectrosc. Radiat. Transfer, vol. 8, 1968, p. 1373.
3685 DERSHEM, E.; AND SCHEIN, M. Phys. Rev., vol. 37, 1931, p. 1238.
3694 SAMSON, J. A. R. Phys. Rev. Lett., vol. 22, 1969, p. 693.
3754 HUDSON, R. D.; CARTER, V. L.; AND YOUNG, P. A. Phys. Rev., vol. 2, 1970, pp. 643–648.
3761 MARR, G. V.; AND AUSTIN, J. M. Proc. Phys. Soc. London (At. Mol. Phys.), Ser. 2, vol. 2, 1969, p. 107.
3764 HEPPINSTALL, R.; AND MARR, G. V. Proc. Roy. Soc. London, vol. A310, 1969, p. 35.
3765 MARR, G. V.; AND AUSTIN, J. M. Proc. Roy. Soc. London, vol. A310, 1969, p. 137.
3816 HUDSON, R. D.; CARTER, V. L.; AND YOUNG, P. A. Phys. Rev., vol. 180, 1969, p. 77.

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